DESIGN OF PERSONALIZED AIR PURIFIER SYSTEM INTEGRATED WITH PROTECTIVE FULL FACE HELMET FOR A COMMUTER ON TWO WHEELER

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CERTIFICATE

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It is certified that the work contained in the thesis entitled "*Design Of Personalized Air Purifier System Integrated With Protective Full Face Helmet For a Commuter On Two Wheeler*", by Mr. Umakant Soni , has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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Abstract

There is serious threat to the health of the commuting population of the major cities of India due to worsening air quality. This threat is more significant for a section of the population using two-wheelers to commute to their office daily. As they end up traveling in the worst air quality for one to two hours daily for close to 250-300 days a year. Unfortunately, the available solution in the form of pollution masks is woefully inadequate. Further due to helmet being mandatory in a metro city like Delhi, commuters are increasingly looking for a solution that can be used with the normal protective helmet.

Specifically, the ' House of Quality' approach to the problem of building a globally competitive product with participation from the consumer is successfully implemented. The innovative approach adopted can be suitably modified to promote technological solutions in form of products in diverse fields.

Development of a globally unique solution in form of personalized air purifier system integrated with full-face helmet has been accomplished. The product solves most of the problems faced by commuters on two-wheelers with regard to air quality.

The design developed has features such as, forced airflow using a special fan, a curved venturi profile of the air path through the air purifier to provide clean air during cruising, reasonably high gaseous contaminant removal with filter charge using ACF coated with glycerol and high particulate removal efficiency, which increases with time, uniquely designed easy, to change filter charge with the use of unique filter strip concept.

The product is user-friendly and has a potential of bringing relief in form of clean air at low cost to an estimated 40 million users in India.

Chapter -1
INTRODUCTION

A comprehensive definition of air pollution was made by the Indian Standard Institute(now BIS) under IS-4167-" The presence in ambient atmosphere of substances, generally resulting from the activity of man, in sufficient concentration, present for a sufficient time and under circumstances which interfere significantly with the comfort, health, or welfare of persons or with the full use of enjoyment of property". It has been found that in the most of the megacities of the world, motor vehicles are a major source of pollution, and in nearly half of them, it is the single most important source. Most of the cities are having overwhelming traffic-created problems, with high carbon monoxide, hydrocarbon, nitrogen oxides and lead emissions. In India out of 70 cities, in 69 cities, the air quality was moderately, highly or critically poor round the year. In 33 cities, that is, in about half of the all the cities monitored, the air was moderately poor round the year and they had days when the air quality was above critical [1].

a) Despite legislative and institutional frameworks and a pollution control statement, precious little has changed on the Indian pollution front, which continues to worsen rapidly over time. The dramatic rise in air pollution in most Indian metropolises over the last one decade is a direct result of an inefficient state, both in terms of its balancing responsibilities- that is bringing about balance between environment and development, and precautionary activities – that is, taking action before the damage is done.

It has been revealed by a series of studies that vehicular technology, poor fuel quality, poor vehicular maintenance and non existent planning is the main cause of high levels of pollution [2]. The WHO (World Health Organization) specifies that there are no safe levels for airborne benzene. Unleaded fuel is India has very high levels of benzene, which is added to enhance the anti knocking properties of fuel. But benzene is a definite carcinogen and along with lung cancer and leukemia, it causes damage to the central nervous system, and leads to hematological and immunological effects. Particulates have been associated with

increased respiratory diseases (asthma, bronchitis, emphysema), cardiopulmonary disease (heart attack), and cancer [2].

While this continues and people are affected in every other way one particular segment of the population is under attack from vehicular pollution and seems so far to have been ignored by the researchers. This segment consists of the ever-increasing working class population especially in metros and cities waiting to turn into industrial metropolis. This particular segment has, by and large middle class background. These persons usually prefer using two-wheeler to commute to work. The distances usually are large and they end up spending more that two hours daily to commute (on an average). These two hours involve traveling in peak load of pollutants. This is not just once but continues for most of the days round the year. This particular segment is very much exposed to a very high concentration of air contaminants. This is already reflected in a marked increases in cases of bronchial asthma and cancer.

There can be various ways in which this problem can be solved:

1. We can make stricter emission standards and force all the manufacturers to follow them.
2. We can improve the existing engine technologies to reduce emissions.
3. We can use cleaner fuels.
4. We can have a better public transportation system.

As is clear, this problem has got particular dimensions that will need to take into account practical conditions. In the first strategy the catch is that for all practical purposes the implementation of the environmental norms has been only on paper. As a result we have age-old polluting taxies on the roads on the most of the metros. Furthermore, as the norms are not uniformly followed in all the cities, this is going to result in mass migration of the polluting vehicles from the cities having stricter norms to the cities having much weaker implementation arms.

Major amount of money has been invested in this aspect and in the long-term, is worth spending. But as of now there is no significant improvement in either the design of engines or related parts like catalytic converters that can give us the assurance that emission is well below the standards.

In India there are vehicles that have histories well traced into the three and four decades. Thus there are going to be a lot of old vehicles in India for at least 10 to 15 years. So to expect air quality to improve very soon, is indeed a pipe dream.

One of the reasons that have been cited as one of the major contributors to the problem is the quality of the fuel being used. This aspect is however very complicated and its effect overall impact is not yet clear.

Developing a good public transportation system and maintaining it is not an easy task. Only Calcutta and Mumbai to some extent can be said to have some sort of public transportation system. But the population pressure on the metros has overwhelmed even these. The Rest of the metros are at least 10 to 15 years away from having a public transportation backbone.

So for the coming 10-15 years what should the people, who have to suffer the nightmare having no protection from diseases caused by deteriorating environmental conditions, do? That is why the concept of clean air manufacturing system is so appealing. Just as one can get unpolluted water using various water purifiers, we can also do the same for air and avoid the consequences of the inhaling polluted air at a very nominal cost. If we integrate this clean air equipment with a safety device like a helmet then it will solve the problem of poor air ventilation inside the full-face helmet, thereby encouraging its use.

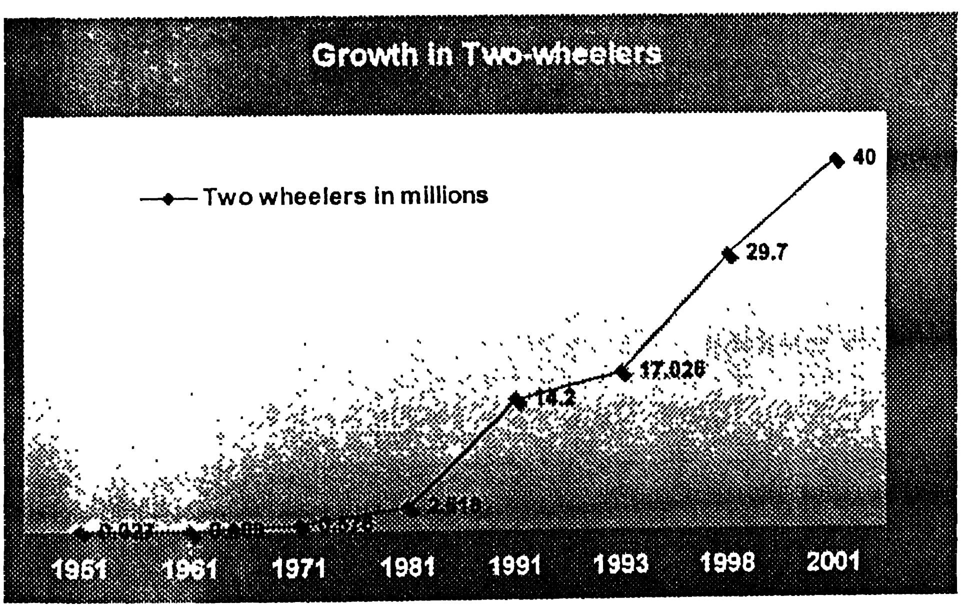


Fig 1.1 Growth in number of two-wheeler in India (Association of Indian Automobile manufacturers).

Chapter -2
BACKGROUND INFORMATION

This chapter a description of basic principles involving pollutant control and typical devices in use are given. This is followed by the problem analysis. The principle and application of various techniques used in various prototypes are also given including literature about filter medium employed.

2.1 Basic principles used in particle and gas capture

2.1.1Adsorption: -

The forces that hold atoms, molecules, or ions together in the solid state exist throughout the body of a solid and at its surface. The forces at the surface may be considered to be " residual" in that they are available for binding other molecules which come in contact with it. Any gas, vapor, or liquid will, therefore, adhere to some degree to any solid surface. This phenomenon is called adsorption, or sorption, the adsorbing solid is called the adsorbent, or sorbent and the adsorbed material is the adsorbate, or sorbate. Adsorbed matter may also condense in the submicroscopic pores of an adsorbent; this phenomenon is called capillary condensation. A molecule that moves to and is held at the surface of a solid loses the energy of its motion; adsorption is therefore always an exothermic, or energy- releasing process.

The quantity of the material that can be physically adsorbed by a given weight of adsorbent depends on the following factors:

a) the concentration of the material in the space around the adsorbent,

b) the total surface area of the adsorbent,

c) the total volume of pores in the adsorbent whose diameters are small enough to facilitate condensation of adsorbed gases,

d) the temperature,

e) the presence of other gases in the environment which may compete for a place on the adsorbent,

f) the characteristics of the molecules to be adsorbed, especially their weight, electrical polarity, size, and shape,

g) the electrical polarity of the adsorbent surface.

Maximum capacity for adsorption of a given substance is favored by a high concentration of the substance is the space adjoining the adsorbent, a large adsorbing surface, freedom from competing substances, low temperature, and by aggregation of the substance in large molecules which fit and are strongly attracted to the receiving shapes of the adsorbent [3].

2.1.2 Filtration and types of capture:-

Mechanical filtration of particulate matter from an air stream can be achieved by several mechanisms, depending on the size and character of the particles.

The main classically accepted methods are:

1. Impaction, which encompasses interception, settling and inertial forces.
2. Interception.
3. Diffusion.
4. Electrostatic forces.

One is preliminary dealing with "depth" or "bed" type mechanical filters and there exists a very wide selection of different types of filter media available. One can, however, broadly classify them into three main groups in which the mechanism of collection previously mentioned play their particular role.

2.1.3 Impaction

The first group relies almost entirely on direct impaction with a small addition from the effects of interception. Filter beds of this type usually have a very open matrix, giving low pressure drop characteristics. In order to achieve reasonable efficiency, the filaments of the matrix are treated with a suitable wetting agent, such as oil, which greatly increases the

retention of particles. These filters are particularly effective against coarse materials where the inertia effect (kinetic energy) imparted to the particle causes it to remain on a straight line or path instead of following the streamline flow round the filaments.

These filters are capable of accepting a considerable dust load, depending upon the depth and type of construction, but as the wetting agent becomes absorbed by the dust, so the retention capability falls off and an increasing amount of dust passes through. Filters of this type are referred to as having reducing efficiency, with a low rise rate in pressure loss, with increase in dust load and virtually non-clogging. If these filters are used dry, they will have a very low retention efficiency.

2.1.4 Interception

In the second group, the packing density of the filter medium is increased by employing fine fibers, which reduces the size of the voids through the depth of the bed and greatly increases the retention of soot and fine dust particles which range between 1 and 5 microns. Inertial effects on particles in this size range is not very great, and the main mechanism of collection is by interception. The particles tend to follow the streamline flow around fibers and as they pass very close to a fiber they are intercepted and retained on the fiber surface.

There exists a very wide selection of filter materials available in this group, such as felts, waddings and bonded webs made from natural, mineral and man-made fibers. Density and depth of bed can vary from a lofted graded open structure down to a tightly packed fairly thin layer. In addition to the packing density, the cross sectional shape and surface texture of the fiber also aids in retaining particles.

By using finer diameter fibers and increasing the packing density of the medium so that collection efficiency by interception is increased a higher proportion of the sooty particles in the 1 to 2 micron range will be collected. It will be appreciated that as the fibers become finer in diameter and bed density increases, the resistance to airflow increases. It therefore becomes necessary to utilise larger areas of filter media in order to reduce the velocity through the media consistent with a low initial resistance. This can be achieved by employing different configurations of construction, such as deep pleats, bags, W form, etc.

These compacted waddings, felts and woven fabrics are generally used dry, because the voids are so small that the coarse particles can be collected by screening.

2.1.5 Diffusion

The third group encompasses very dense materials, which are the most efficient filter media. Extremely fine fibers are used to the order of a few microns in diameter and including some sub-micron sizes as well[4].

Usually, a blend of fine and slightly coarser fibers are used and the medium carefully controlled during manufacturing to ensure a uniform distribution throughout the depth. The main function of the coarse fibers is to prevent the fine fibers meeting. By increasing the proportion of fine fibers the more efficient the filter medium but it is also accompanied by a corresponding increase in resistance to airflow.

This very fine and dense media has a vast contact area offered by the mass of fine fibers; the voids between fibers are very small and are used for "high efficiency" collection of particles below 0.5 micron where the mechanism of collection is by interception and diffusion, or Brownian motion.

As the particle size decreases so the interception efficiency decreases, until below 0.5 micron Brownian diffusion predominates. Brownian motion is when a particle does not follow any particular flowline, but diffuses across the flowline, thereby increasing the probability of contacting a fiber.

There has been a great deal of research work carried out on the filtration of sub-micronic particles and it is generally accepted that particles between 0.3 and 0.5 micron have the maximum penetrating power, as at this particular site the effects of interception area at a minimum.

Suitable high efficiency media, being very dense, have a high resistance to airflow, and in order to achieve low pressure drop characteristics, one of the most widely used forms of construction is to fold the paper medium into deep pleats over corrugated separators. By producing a filter pack in this manner it is possible to employ over $20m^2$ of media in a box size 600mm. x 600mm. x 300mm.

2.1.6 Electrostatic phenomenon

The retention of particles by electrostatic phenomena is not generally considered to exert any influence on filtration efficiency, but with some media the effects are relevant.

There are some "self charging" electrostatic filters which comprise a bed of either fibers or shavings of a high resistivity plastic, such as polythene, polystyrene, terylene, etc.

The theory of such filters is obscure, but it is generally accepted that electrostatic charges are built up in the media as a result of frictional effects of air and particles passing across the fiber surfaces. As the charge builds up, so the particles are attracted towards the fibers, some being retained and others increasing the charge further.

The mechanism of retention is not readily known as the opposite charges of the dust and fibers would probably neutralise one another. Molecular attraction is probably the main mechanism of retention and it is known that small particles are retained more positively than coarser ones. Coating fibers, such as wool with charged resin particles provides another type of electrostatic filter. The media is produced in the form of a corded lap and charging of the resin particles is created by frictional effects during the cording process. The resin particles are negatively charged, whilst a positive charge is induced on the adjoining portions of the fibers. Dust is attracted to the resin coated fibers and consequently the radius of action of the fibers in removing particles from the air stream is greater than that untreated fibers.

To achieve any permanent benefits from electrostatic effects the media must remain dry because, if moisture is present the charge leaks away.

In addition to self-induced electrostatic effects in filter media, there is the accepted conventional electrical power generated electrostatic precipitator, commonly known as the "electronic air cleaner".

The most commonly used electronic air cleaner is a two-stage unit. The first stage is an ionised section, utilizing fine wires, and earthed parallel plate electrodes. A high voltage potential is applied between the positive ionised wire and electrode, which creates an electrostatic field of considerable intensity.

The stream of electrons flowing between ionising wire and electrode produces what is known as a corona discharge. The air molecules which flow past, are charged or ionised by the electrons, some are positively charged and others negatively charged. When dust particles pass through the ionising section the molecules collide with them and impart an electrical charge.

The second stage is a series of parallel plates which are charged alternatively positive and negative. As the charged dust particles pass between the plates, they are drawn diagonally across the airstream to the collector plate. There are a number of factors affecting collection efficiency, such as mass, size, shape, electrical resistivity and terminal velocity of the particle.

Generally speaking, electronic air cleaners have a high retention efficiency on a size range of particles from sub micron to about 25 micron which puts them on a par with the highest grade of media filters.

Efficiency falls off progressively with an increase in particle size and with increase in velocity. To assist in the retention of particles, the collector plates are coated with water-soluble oil.

2.2 Mobile pollution sources

Motor vehicles are by far the major mobile pollution source. The sources of pollutants from motor vehicles are crankcase and exhaust emissions and evaporative emissions from the fuel tank and carburetor[3].

2.2.1 Crankcase Emissions

Crankcase emissions occur when some of the air-fuel mixture within the cylinder is forced past the piston rings as so-called "blowby." If uncontrolled, blowby vented to the air from the crankcase can represent about 25% of the total hydrocarbon emissions of an engine. The hydrocarbon concentration of blowby does not vary widely among vehicles and among operating modes because blowby is mainly the carbureted air-fuel mixture. Its volume, however, varies over a wide range because pressures in the cylinder change according to operating mode. Blowby rates are high during the compression and power stokes; lowest during deceleration and idle. There are negligible amounts of pollutants other than hydrocarbons in blowby.

Since diesel engines compress only air (and small amounts of residual exhaust gas), blowby contains very low levels of pollutants, e.g., hydrocarbons.

2.2.2 Evaporative Emissions

In the gasoline-powered vehicles. gasoline vapors can escape from the fuel tank and carburetor. The amount escaping depends upon fuel compositions, engine operating temperature, and ambient temperature. Evaporative losses from the fuel tank are strongly influence by the ambient temperature and exposure of the tank to the sun, the atmosphere, and pavements. These losses can be very high when the ambient air temperature approaches the boiling point of the gasoline.

The evaporative losses from the carburetor take place mainly during the "hot soak' period when the carburetor is heated by the hot engine after the engine has been turned off and no longer has its radiator fan in operation. Ambient temperature has less effect on evaporative losses from the carburetor. If uncontrolled, evaporative losses are about 15% of the total hydrocarbon loss from a vehicle. There are no pollutants than hydrocarbon in the evaporative loss.

2.2.3 Exhaust Emissions

The exhaust is the source of most of the hydrocarbon emissions-60% from an uncontrolled engine, almost 100% from an engine with crankcase vent and evaporative emissions controls- and practically all the oxides of nitrogen and carbon monoxide emissions. Exhaust products are the result of combustion in the engine under high temperature and pressure. Depending upon fuel composition and fuel additives employed, sulfur dioxide, lead, lead scavenger compounds, oxygenated compounds, particulate matter and other compounds may also be present in the exhaust. The type and quantity of pollutants emitted through the exhaust are strongly dependent on the engine operating modes.

2.3 High Emitter problem

Despite remarkable progress in developing emission control technology, progress in the reducing aggregate emission from the total in use vehicle fleet and hence in improving air quality is much slower. While may of the reasons are suggested like:

(a) Emission test procedures underestimate in-use emissions;

(b) The extremes of vehicle use;

(c) Actual fuel quality variability;

(d) Emissions at extremes malfunction or failure;

(e) Incompetent repair of emission control system component result in a fraction of the vehicle fleet having very high emission level.

While these factors contribute to vehicle emission being higher than thought before; it is last of these that is the most important. This has become known as the high emitter problem[5]. For every model year of the vehicles newer through older, the worst emitting 20 percent or quantile has much higher emission than the rest of the distribution, and when weighted by its fraction of the total fleet, contribute more that half the emissions [6]. And these high emitters are found in all model year vehicles; it is not just the old cars that are high emitters. Our emission control technology, developed with much hard work by engineers over the past 25 years, is very effective in at reducing emissions from most cars on the road for much of their useful life; but its failure to achieve this control in a small fraction of the vehicle fleet offsets a substantial part of the reductions realized in the vast majority of the fleet. Our future efforts to reduce emissions must somehow deal with this reality.

Thus in Indian cities and especially in cities like Delhi, the sheer number of the vehicles makes the problems much more harder to solve. Adding to the problem is lack for space for each vehicle resulting in reduced traffic speed and congestion. This aggravates the problem as pollutants generated don't disperse and come in contact with the vehicle users especially two-wheeler user. This problem is of very much importance at intersections.

Greater reliance on private transport gives rise to another cause for increased emissions. Indian cities have inadequate road space, which cannot accommodate the rise in the number of vehicles. Traffic jams and congestion impede the flow of traffic, reduce the average speed and thus increase emissions. To effectively control vehicular emissions there has to be reduced frequency of idling, cruising, and deceleration caused due to frequent stoppages caused by too many intersections and congested traffic.

2.4 Pollution and its health effects

Major problems occurring due to exposure to gaseous and particulate contamination has been very well documented although the epidemiological studies in Indian conditions have been conspicuous by their absence. The major effects of gaseous contaminants have been summarized in the table 2.4.2.

While the particulate emission problem in commuters has been not very well studied in India although a number of studies has tried to find out the mechanisms by which the pollutants and carcinogens invade the body and cause damages. Internationally there has been good evidence that exceptional episodes of pollution [>1.0 mg/m3 (0.385 ppm) sulfur dioxide and particulates] caused illness and death. There is also a good deal of evidence that sustained lower level of pollution [>0.1 mg/m3 (0.039 ppm) of sulfur dioxide and particulates] for a number of years affects health adversely [7].

The major function of the lungs is the exchange of gases with the environment. The overall function of the respiratory system is to supply oxygen to the tissues of the body and to remove carbon dioxide from the body. This gas exchange is accomplished by a complex system of organs involving many anatomical structures and physiological mechanisms. A normal sedentary adult inhales 3 to 5 liters of air per minute to accomplish the physiologically required gas exchange. During exercise or strenuous work, the rate of inhalation may increase as much as 10 to 20 times that of rest. Ambient air is seldom free form pollutants. Thus, various noxious agents have access to the lungs , which makes it the body organ most frequently affected by airborne environmental pollutants. Some of these toxic agents also affect other body system, such as the cardiovascular system, the central nervous system., the kidneys, and the bone marrow.

Respirable agents may be of different types: pathogens(viruses, bacteria, and fungi) , allergens, gases(e.g., HC, CO, CO2 , SO2, and radon); particulate(e.g. asbestos fibers, silica carbon dust and cotton dust), smoke(e.g., cigarettes, traffic, and industrial), or other chemical agents.

2.4.1 Mechanism of particulate and gaseous pollutant trapping in human body

Toxic gases either react directly on portions of the respiratory tract or are transported to other organs before their effect is registered. Examples of the first type are ozone and sulfur dioxide. Examples of the second type are carbon monoxide and hydrogen cyanide. Highly reactive agents soluble in water (e.g., anhydrous acids and strong oxidants) are apt to damage tissue, while less reactive gases diffuse through tissue to react with endothelial cells. Other gases may also damage capillaries.

Nasal cavity is the principal organ that transfers water and energy to and from respired air. Because the surface of the nasal cavity contains a great deal of water, any toxic gas soluble in water will be removed. Anhydrous acids and sulfur dioxides are more apt to be removed than ozone, owing to the latter's lower solubility in water. The nasal cavity is the body's most efficient wet scrubber. In the tracheobronchial region toxic gases encounter mucus lining the airways. Gases penetrating the mucous lining contact goblet or ciliated cells. Ciliated cells are generally more sensitive to toxins than goblet cells, and reducing the number of cilia per unit area of passageway impairs the clearance mechanism.

The body's response to particles contained in inspired air is entirely different than its response to gases. Clearance is the process by which particles are removed from the lung. Mucociliary clearance is the process by which the conducting airways of the lung remove depositing particles and carry them to the larynx on surface mucus propelled by cilia. Alveolar clearance is the process by which particles are removed by nonciliated surfaces in the gas-exchange region of the lung. Clearance mechanisms include ingestion by macrophage followed by the migration from the lung and the gradual dissolution of the particles[8].

Particle deposit themselves throughout all the regions of the lung through a variety of processes [9],[10]. In the nasopharyngeal region inertial impaction is the dominant mechanism and relatively large particles are removed. Particles removed in the trachea and bronchial tree are removed by a combination of inertial and gravitational settling processes. The larynx affects particle motion because of turbulence created by air passing over the vocal cords. In addition, the particle entrained in the air laving the larynx contact the trachea at localized "hot spots"[11].

Elsewhere in the lung, particles are deposited more uniformly over the airway surface. Submicron particles penetrate the alveolar region and are metabolized by microphage. Particles that are not metabolized remain in the alveoli or may diffuse to other parts of the body, such as the lymphatic system. Particles removed in the nasopharyngeal region enter the digestive tract and pass through the body in a short time. Particles entering the trachea are removed by cilia and mucus and transported to the digestive tract. Particles penetrating the bronchial tree are flushed more slowly. Exactly which particle penetrates which region of the respiratory tract depends upon the breathing rate and volume. Particle deposited in the alveoli are acted upon by one or a combination of four processes.

1. Particles may be phagocytized and passed up the tracheobronchial tree by the mucociliary escalator.
2. Particles may be phagocytized and transferred to the lymphatic drainage system.
3. Particle surface material may be dissolved and transferred to the blood vessels or lymphatics.
4. Particles and some dissolved material may be retained in the alveoli permanently.

There is basic disagreement on the interpretation of the epidemiological data on the health effects associated with the increase in the particle air pollution. Although a strong case has been presented that this association reflects a causal relationship, plausible alternative explanations have also been suggested [11]. A study, entitled the Swiss Study on Air Pollution and Lung Diseases in Adults (SAPALDIA), showed a strong association between long-term exposure to air pollutants and decrements in lung function. It found positive associations between annual mean concentrations of nitrogen dioxide (NO2), total suspended particulates, and tiny pollutant particles (PM10) with reported prevalence of chronic phlegm production, chronic cough or phlegm production, breathlessness during the day or night, and dyspnea on exertion. The magnitude was similar whether the subjects reported respiratory symptoms or were essentially symptom-free [12].

However a very recent studies based on the data showing the effects of five major outdoor-air pollutants on daily mortality rates in 20 of the largest cities and metropolitan areas in the United States from 1987 to 1994 found consistent evidence that the level of PM_{10} is associated with the rate of death from all causes and from cardiovascular and respiratory illnesses. The estimated increase in the relative rate of death from all causes was 0.51 percent (95 percent posterior interval, 0.07 to 0.93 percent) for each increase in the PM_{10} level of 10 μg per cubic meter. The estimated increase in the relative rate of death from cardiovascular and respiratory causes was 0.68 percent (95 percent posterior interval, 0.20 to 1.16 percent) for each increase in the PM_{10} level of 10 μg per cubic meter [13].

The pollutants are particulate matter that is less than 10 μm in aerodynamic diameter (PM_{10}), ozone, carbon monoxide, sulfur dioxide, and nitrogen dioxide.

2.4.2 Economic cost of pollution

The World Bank study is direct in its definition of the problem when it has related the impact of pollution to the health and health cost [14]. According to the study, more than 40,000 Indians are dying early because of polluted air in cities, and these deaths are associated with a economic losses in the range of Rs 595 crore to 5,652.5 crore. Premature deaths due to air pollution is estimated to have gone up from 40,000 in 1991-92 to 52,000 in 1995 in Indian cities – an increase of 30 percent. India is spending Rs 4,550 crore annually to make up for health damages caused by ambient air pollution. Despite this no epidemiological studies have been conducted in India to show its effect on health [15].

Table 2.4.1 ***Estimates of annual health incidences in Indian cities due to ambient air pollution levels exceeding WHO guidelines.*** **Source[14].**

Cities	Premature deaths	Hospital admissions and sickness requiring medical treatment	Incidence of minor sickness
Ahmedabad	2,979	1,183,033	72,177,644
Bangalore	254	135,887	8,326,282
Calcutta	5,726	3,022,786	179,479,908
Chennai	863	461,966	27,859,487
Delhi	7,491	3,990,012	241,958,219
Hyderabad	768	420,958	25,177,173
Jaipur	1,145	520,947	31,708,958
Kanpur	1,894	812,381	49,247,224
Mumbai	4,477	2,579,210	156,452,916
Patna	752	319,242	19,561,109

Table 2.4.2: ***Type Of Pollution And Their Effects***

Pollutant	Major source	Health effect
Carbon mono oxide	All gasoline vehicles- more from those without a catalytic converter	Highest affinity exhibited by haemoglobin, reduces the oxygen carrying capacity of blood and hence increases risk for people with heart diseases. Affects reflexes and thinking. Serious combined effect with other pollutants.
(Unburned or partially burnt) Hydrocarb ons (HC)	Major contributors are petrol vehicles without cat,. Converter, two-stroke engines and fuel pump stations (spillage)	High irritant to eyes. Affects respiratory system. Suspended carcinogenic effect depending on presence of benzene in fuel, converted aromatics and pyro-sythesis to PAH during combustion.
Nitrogen Oxides (NO_2)	More form diesel vehicles and less from petrol vehicles.	Affects respiratory system due to acidic effect. Aggravates asthma and irritant to eyes. When combined with HC and other pollutants can be very harmful.
Particulate matter	Mostly from diesel fuelled vehicles and oil burning in two-vehicles and oil burning in two-stroke engines. Very fine and low in petrol fuelled vehicles.	Affects respiratory system more seriously. When combined with SO2 irritates and impairs breathing. Diesel exhaust particulate contains PAH which are likely to be carcinogenic to human beings.
Lead	Petrol vehicles- Basically from lead in fuel.	Affects circulatory, reproductive and nervous system- mental functions of children- and increases risk to people with high blood pressure. Affects respiratory system.
Sulphur di-oxide (SO_2)	Both petrol and diesel- basically from the sulphur level in fuel.	Directly affects the respiratory system. Very high irritant. When combined with particulate matter, affects people with chronic bronchial and heart diseases.
Benzene	Mostly from fuel directly. Occasional formation in combustion or conversion of aromatics	Known carcinogenic. Direct health effect on continued exposure. Reproductive problems and birth defects are likely.
Ozone	Mostly from HC and NO_x	Irritation to respiratory organs and eyes. Decreases the resistance power to infections. Aggravates illness.

Chapter –3
OBJECTIVES AND SCOPE OF WORK

3.1 Statement of the problem

From the discussion in the previous chapters it is apparent that there is serious threat to the commuting population of most of the major cities of India health. This threat is more significant for a section of the population using two-wheelers to commute to their office daily. Unfortunately, the available solution in form of pollution masks is woefully inadequate. Their lack of effectiveness coupled with disregard for Indian climate in their design make then unpopular with the commuting population. Further due to helmet being mandatory in a metro like Delhi, commuters are increasingly looking for a solution that can be usable with the normal protective helmet.

3.2 Objectives and scope of the work

Developing a prototype demands quite a different set of paths all in the end leading to the final destination, a workable prototype that satisfies the design objectives. Keeping this in mind, following objectives was finalized: -

1. Study of available commercial device related to this particular problem, mainly including commonly available pollution masks and various other types of respirator.
2. Development of a proper design methodology based on 'House of Quality' approach; suitable for this problem, to enable exploratory prototyping.
3. Design iterations based on the design methodology developed, while incorporating the feedback generated in the testing of previous iterations.
4. Suggestions for the final device prototype design based on iterations.
5. Development of the final prototype with accuracy with regards to final working dimensions and it's testing on the field for workability.

Chapter -4
STUDY OF RESPIRATORY PROTECTION UNITS

4.1 Respirator guidelines and types

4.1.1 Definition

A respirator is a piece of equipment that reduces chemical exposures by preventing contaminants from being inhaled. There are many different types of respirators, all useful in specific situations. Respirators are composed of a facepiece that seals out contaminants, and a device that provides clean air. Two types of respirators are used for obtaining clean air:

1. Air purifying - Filters are used to purify the air
2. Atmosphere supplying - A supply of clean air is provided from a tank or hose

Respirators differ in how much protection they afford. Industrial hygienist have developed a scoring system to rank different types of respirators. Each respirator is given a score based on the amount of protection it can provide. This score is known as a protection factor (PF).

4.1.2 Protection Factors

The key to understanding respirator protection is to realize that all respirators leak to a certain degree. The amount of leakage depends on how well the facepiece seals to the face. A leak in the facepiece means that contaminated air can enter the facepiece. The act of inhaling creates negative air pressure inside the facepiece that results in a slight suction effect. The suction can draw in contaminated air. These leaks compromise the protection given by the respirator. Breathing contaminated air can lead to adverse health effects depending on the type and amount of chemical.

Respirators are tested for leakage by measuring the contaminant levels both outside and inside the respirator. Using the ratio of these two measurements, a PF is assigned. A PF is based on the assumption that the respirator is working properly, is worn correctly, and fits

the wearer. Respirator PFs range from 5 to 10,000. **The lower the PF, the lower the protection. The higher the PF, the higher the protection.** The goal of a respirator is to reduce the amount of hazardous chemical inside the mask to below the Occupational Safety and Health Administration (*OSHA*) permissible exposure limit (*PEL*). Respirators must be chosen to ensure that wearers are never overexposed while wearing the respirator.

4.1.3 Maximum Use Concentration

Maximum use concentration (MUC) is that level of contaminants which. if exceeded. will cause a wearer to be exposed above the PEL because of leakage into the respirator. The MUC is the highest concentration of contaminants in which a respirator can be used safely. At no time should a respirator be used in an environment that exceeds the MUC. The MUC is calculated by multiplying PF times PEL.

1. **Types of Respirators**

4.1.4a Air purifying respirators

Air purifying respirators (*APRs*) clean the air a wearer breathes by removing or filtering a contaminant from the air before it enters the wearer's lungs. APRs have two components-the face piece and the filter or cartridge. When a wearer inhales, contaminated air is pulled into the respirator through a filter or cartridge attached to the face piece. The filter or cartridge removes the contaminant from the air before it enters the inside of the respirator through the inhalation valve. When the wearer exhales, air from the lungs reverses the airflow through the face piece and out a separate valve called the exhalation valve.

4.1.4b Negative Pressure Respirators

APRs are commonly called negative pressure respirators. They depend on lung power to pull the air through the filters. The suction created when a wearer inhales draws air into the respirator. This suction creates a momentary negative pressure. During inhalation, the negative pressure brings contaminants into the face piece through leaks and improper seals. During exhalation air is blown out and a positive pressure is created in the face piece. It's important to remember that negative pressure respirators must only be used if the oxygen level in the work place is above 19.5%.

4.1.4c Disposable Paper Masks and Quarter Masks

Many wearers are familiar with the disposable paper masks. They are the throwaway type, and do not seal to the face well enough to provide a good fit. Laboratory tests done with mannequins show PFs of 5 to 10. However, studies done under actual work conditions show even lower PFs. The leakage for this type of mask is too severe. Furthermore, the paper of a disposable mask is only effective for large-particle dusts. Gases, vapors, fumes, and fine dusts, such as asbestos, may pass right through the paper. These masks are not to be used for asbestos abatement operations.

The quarter mask is normally a rubber mask, which fits from the top of the nose to the top of the chin. It uses cloth or cartridge filters. The PF is rated at 5. This type of mask it is not to be used for asbestos abatement work.

4.1.5 Air purifying respirators

4.1.5a Half-Face Air purifying respirators

The half-face APR is made of rubber or plastic. It fits from the top of the nose to under the chin. Figure 4.1.1 shows a typical half-face APR.

Figure 4.1.1 Half-face air-purifying respirator; Source (NIOSH).

A half-face APR uses one or two filter cartridges attached to the facepiece to filter the air. The fit given by the respirator rates a fairly low PF of 10. These respirators can be used in some situations, but the industrial hygienist must be confident in his or her knowledge of the level of asbestos exposure that will occur, and how high the levels can potentially get.

Other limitations of the half-face APR are:

- No eye protection - The respirator does not cover the eyes. Goggles or face shields must be used.

- Cartridge life problems - The filter has a limited ability to remove chemical contaminants. When the saturation point is reached, chemicals begin to pass through the filter. This condition is called breakthrough. Some chemicals have poor warning properties so a wearer will not notice any chemical smell when breakthrough occurs. This situation can lead to serious exposure problems. As a result, the half-face APR cannot be used for chemicals with poor warning properties. Some filters have end of service life indicators (ESLI), that change color when a filter is used up. However, few indicators have been successfully developed and most are for specific chemicals only.

- Cartridge efficiency problems - There are many types of organic solvents, but only one type of organic solvent filter. Studies show that while this filter is very efficient for some solvents, it allows other solvents to pass through quickly. For example, the organic vapor filter lasts 143 minutes in an atmosphere with a concentration of 1,000 PPM of 1-nitropropane. But at 1,000 PPM of ethyl chloride, the filter only lasts 5.6 minutes. Therefore, the half-face APR and filter are not used for solvents that have rapid breakthrough. However, not all solvents have been tested.

- Oxygen limitations - The half-face APR can only be used when sufficient oxygen is present in the work atmosphere. Normal breathing air contains about 21% oxygen. It can be less in confined areas with other chemicals present.

- Not suitable for areas of unknown chemicals or levels - The protection offered by this respirator is limited, therefore, it cannot be used for unknown situations. The levels might exceed 10 times the PEL or different chemicals might go right through the filter to cause health effects. Specific cartridges are manufactured to protect against specific chemicals and may not be used in some mixed chemical atmospheres.

- Not suitable for concentrations that are immediately dangerous to life or health (IDLH) - Under no circumstances should an APR be used in an IDLH atmosphere. For most chemicals this is not an issue, because the MUC is lower than the IDLH level. But there are exceptions. For some chemicals, the IDLH is lower than the MUC and the respirator can not be used if the level approaches the IDLH level.

- Humidity problems - Some studies have shown that breakthrough occurs more quickly under conditions of high humidity.

- Usage - The useful life of a cartridge is limited once the filter is opened. Usually cartridges are discarded after each use, not to exceed one shift. If breakthrough occurs and is noticed, then cartridges are changed at that time even if it's less than one shift.

Half-face respirators are the minimum type used for asbestos abatement work.

4.1.5b Full-Face APRs

A full-face APR is made of rubber or plastic. It covers the whole face, starting at the forehead, down over the temples and the eyes, and under the chin (Figure 4.1.2). The full-face APR has a PF of 50 because it's easier to get a good seal across the forehead than across the nose. Also, the respirator is held more securely in place because it has a harness instead of straps. The full-face APR uses the same types of filters as the half-face APR, so it also carries the same limitations. It does protect the eyes, although it has a tendency to fog up.

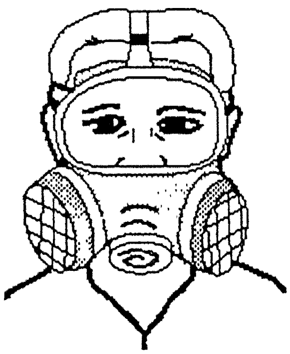


Figure 4.1.2 Full-face air-purifying respirator. Source (NIOSH)

Some full-face APRs can use larger chin, chest, or back-mounted canister-type filters. These filters are larger, and have fewer limitations. There are several filters available in larger sizes for full-face APRs that are not available for half-face APRs. Since canisters are larger than cartridges, they have higher capacities. Even though full-face APRs protect more than half-face APRs, they still do not offer enough protection to be used in IDLH conditions.

4.1.5c Powered Air Purifying Respirator

The powered air purifying respirator (*PAPR*) uses the same type of facepiece and filters as the full-face APR (Figure 4.1.3). However, the full-face APR is a negative pressure

APR and the PAPR is a positive pressure APR. The PAPR uses a small lightweight battery-operated blower to draw air through filters and into the facepiece. This makes it more comfortable to use because less work is required to breath. Also air is blown across the face to provide some degree of cooling. Because the PAPR seals the face in the same manner as the full-face negative pressure APR, the protection factor assigned by OSHA (for exposure to lead) is 50.

Figure 4.1.3 Powered air-purifying respirator. Source (NIOSH)

Although the PAPR is an improvement over the negative pressure full-face APR, it has two limitations:

1. Weak batteries cause the fan motor to slow down. The batteries are designed to last a full shift, and then require a full 8-hour charge. PAPR units come with a small flow meter that enables the wearer to test the air flow and thus the battery charge.

2. Under heavy work conditions a wearer can use more air then the PAPR provides, creating negative pressure in the mask. This condition is called *over breathing* a PAPR. When overbreathing a PAPR occurs, the level of protection provided by the respirator will be reduced.

Some PAPRs have loose-fitting hoods and helmets instead of face masks. While these hoods are comfortable, they provide less protection. OSHA assigns a PF of only 25 for loose-fitting PAPRs.

4.1.5d Filtering Devices

Air purifying respirators are manufactured with two basic types of filtering devices:

1. Particulate filters

Particulate filter respirators use a filter made of a fibrous material to capture contaminant particles before the air reaches the wearer's lungs. The particles are pulled through the filter as the wearer inhales, and become trapped by the fibers of the filter. Particulate filter respirators are used for protection against particles of dusts, fumes, and/or mists. Typical examples include welding fumes, oil mists, silica, asphalt fumes, and asbestos.

2. Vapor and gas removing canisters and cartridge

Vapor and gas removing cartridges and canisters are used with APRs to protect wearers from exposures to air that is contaminated with toxic vapors and gases.While particulate filters are effective for nearly all types of particles, gas and vapor removing cartridges and canisters are designed to protect against specific individual contaminants. Examples include carbon monoxide, ammonia gas, or combinations of gases and vapors, such as acid gases or organic vapors.

Contaminants are removed as inhaled air enters the cartridge or canister and passes through a granular material called a sorbent. The sorbent absorbs contaminants from the air, and provides protection to the wearer from the toxic effects of the gas or vapor.

Materials used as sorbents include activated charcoal, silica gel, and various mixtures of specific chemicals that will capture the contaminant. Initially a gas and vapor sorbent is 100% efficient in capturing a contaminant. As the sorbent is used up, the efficiency decreases. When the sorbent is exhausted, the contaminant passes completely through the sorbent and into the facepiece where it is inhaled by the wearer. This loss of capturing efficiency is opposite to particulate filters which become more efficient as particles collect on the filter.

Sorbents for gases and vapors are packaged into either cartridges or canisters. The only difference between a cartridge and a canister is the amount of sorbent they contain. Cartridges are designed to be used singly or in pairs on quarter-, half-, and full-facepieces. The amount of sorbent contained in a cartridge is small, making their useful lifetime short in duration. This limitation restricts the use of cartridges to low concentrations of gases and vapors.

Canisters contain larger amounts of sorbent material than cartridges. Therefore, they can be used in situations where the workplace air concentration of gases or vapors is high. Canisters are designed as chin, front, or back-mounted devices. When a canister is used with a facepiece, the respirator is called a gas mask.

Cartridges or canisters are designed for either one specific type of gas or vapor, or a combination of gases and vapors together. In addition, some cartridges and canisters are manufactured to protect against both gases and vapors, as well as particulates by combining particulate filters with sorbent materials. When filters are combined with gas and vapor sorbents. the filter is located in the inlet side of the cartridge. It is either built into the cartridge itself or held to the outside of the cartridge by a snap-on cover.

Gas and vapor cartridges have short useful service times. Therefore, it is recommended wearers discard their cartridges or canisters at least daily, even if no odor, taste, or irritation is detected. Some canisters are designed for use against substances with poor warning properties (no odor or taste). These canisters have end of service life indicators (*ESLIs*) that show the canister is exhausted and needs to be replaced. For example, cartridges used for mercury have ESLIs because mercury has poor warning properties that are not readily noticed by a wearer being exposed.

4.1.6 Atmosphere supplying respirators

There are two types of atmosphere supplying respirators -air line respirators and self-contained breathing apparatus (*SCBA*).

Both types of respirators supply clean breathable air to the wearer and do not depend on filters. With an air line respirator, air is delivered by a hose connected to a compressor. The compressor is equipped with a filtering system that purifies the air. The air for an SCBA is contained either in a compressed air tank or cylinder. The air in the tank or cylinder is under pressure. Regulators are used to reduce the pressure and control the flow of air into the facepiece.

4.1.6a Air Line Respirators

Air line respirators supply air to a facepiece through a length of hose. The hose is connected to either a compressed air cylinder or a compressor that is equipped with equipment to purify the air. The air supply can be used to pressurize the respirator to achieve

a high PF. With a pressure demand regulator, a PF of 1,000 can be typically obtained. The air line respirator, shown in Figure 4.1.4 is being used more and more for lead removal. It does however have the following limitations :

- The air line impairs wearer movement, and cannot exceed 300 feet in length according to regulations. Wearers must carefully retrace their steps coming off of the job.

- The air line can be damaged. Rough or sharp surfaces can puncture the line. Chemicals on the ground may deteriorate the rubber hose. Falling drums, vehicles and heavy equipment can also damage the air line.

- The location of the system air compressor. The compressor must be located away from potential chemical or contamination hazards. All filters and alarms must be working properly and the system must be maintained according to the manufacturer's recommendations.

Due to the limitations of air line respirators, they are often used with a small bottle of air for escape purposes. The bottle contains a 5 to 10 minute air supply. When this escape bottle is provided, OSHA assigns the unit a PF of 2,000. Escape bottles are required for air line respirators being used in IDLH atmospheres.

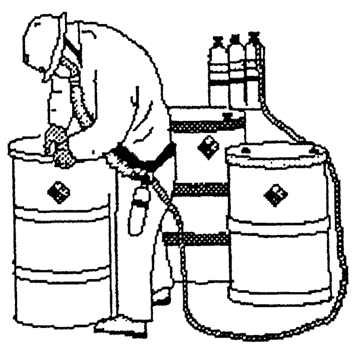


Figure 4.1.4 Airline respirator. Source (NIOSH)

4.1.6b Self-Contained Breathing Apparatus

A self-contained breathing apparatus (*SCBA*) consists of a facepiece and regulator mechanism connected to a cylinder of compressed air that is worn by a wearer (Figure 4.1.5

). SCBAs are commonly used during the most hazardous aspects of waste site jobs because they have a high PF. With an SCBA, a wearer doesn't have air line problems. Wearer training is essential to the safe use of SCBAs.

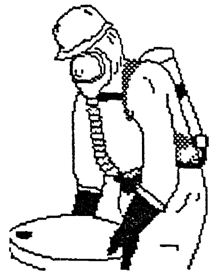


Figure 4.1.5 Self-contained breathing apparatus. Source (NIOSH)

4.2 Study of Commercial Devices

There are a large number of personal protection devices that are manufactured and sold by manufacturers world wide which fall in the categories outlined above. Here all those device are being listed which were studied as to ascertain the kind of design employed and in some cases incorporation of some aspects of their peculiarities during design iterations. This was done to reduce time to completion.

4.2.1 Anti-Pollution Masks and disposable masks

There are various manufacturers worldwide, which are manufacturing pollution masks for the usage on the streets. One of the leading manufacturers of the face masks are Respro (UK) Ltd.

(a) (b)

Figure 4.2.1a Anti-pollution masks with adjustable clip (Source: Respro. (UK) Ltd.)

Figure 4.2.1b Disposable anti-pollution masks with slip. (Source: Survivair Inc. USA)

The Respro Bandit anti-pollution scarf combines protection from the sandblasting effect that dust carried in the wind has on the face, with filtration protection against the inhalation of vehicle pollution.

The filter material, which is strategically placed around the breathing area is laminated within specifically designed 100% cotton scarf, is fully washable and has been made to last for at least six months whilst being used on a daily basis. The Respro Bandit scarf offers the best level of pollution protection currently available on the market

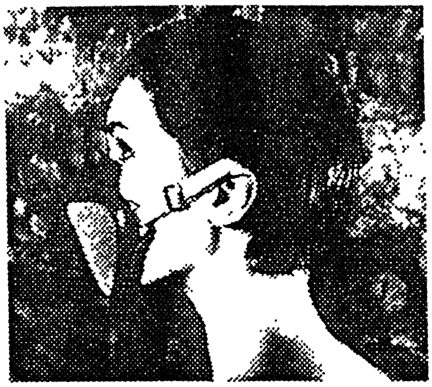


Figure 4.2.2 Anti-pollution masks. Source Respro Corp.

The Respro Sportsta (Fig 4.2.2) mask combines the highest filtration performance associated with sub-micron particulates such as pollen dust, with a lightweight aerated outer shell. Two exhalation valves (Fig 4.2.3) come as standard kit on the Sportsta mask ensuring easier breathing. The Sportsta mask is a fully ventilated mask, offering the coolest performance and the highest protection factor against sub-micron particulate material.

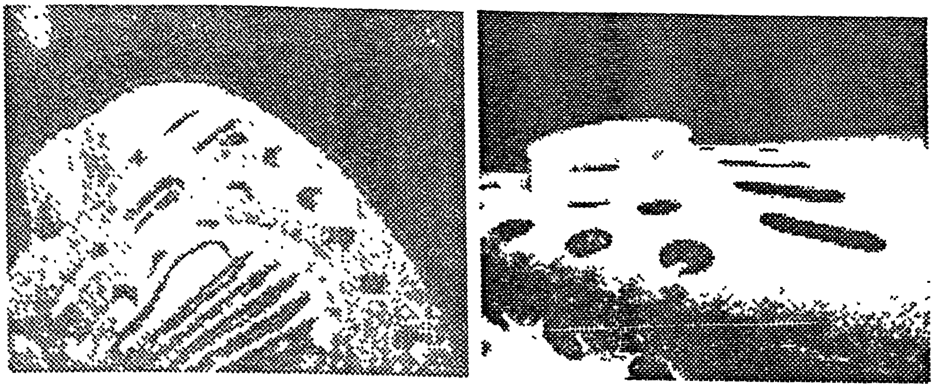


Figure 4.2.3 various types of exhalation masks. (Source: Respro (UK) Ltd.)

4.2.2 Air purifying respirators (APRs)

Air purifying respirators are more commonly used in industrial application rather then in day to day life because of their size and sufficient training required to use them. One of the major corporations manufacturing them is 3M corp. USA, which manufacturers many types of air purifying respirators, including both half faced air purifying respirators (fig. 4.2.4) and also full face air purifying respirators (fig. 4.2.5). These two types are far too bulky to be useful in integration with protective helmets.

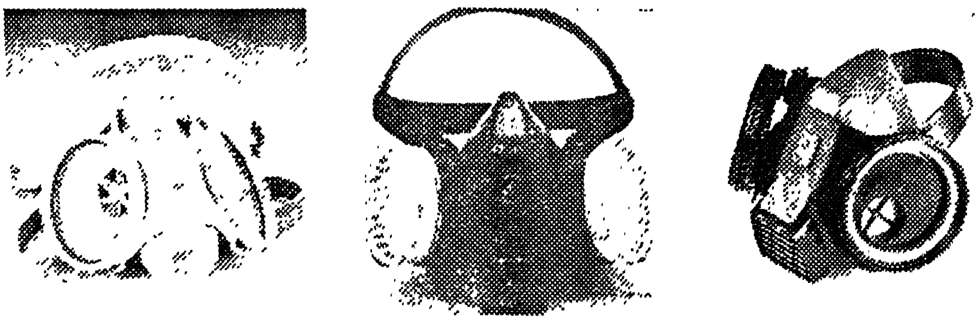


Figure 4.2.4 half face-purifying respirators. Source 3M corp. USA.

Figure 4.2.5 full face air purifying respirator. (Source: Survivair Inc. USA and 3M corp. USA)

4.2.3 Powered air purifying respirator

Powered air purifying respirator uses a blower to force air mass through a set of filters. Figure 4.2.6 shows one such respirator. But these respirators are bulky and used in extreme conditions where a respirator with higher PF is required.

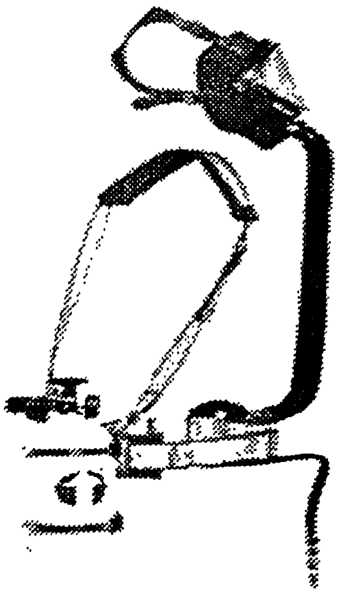


Figure 4.2.6 Powered air purifying respirator, Survivair, Inc. USA.

Chapter -5
DESIGN ITERATIONS

5.1 Design methodology

Developing a product is, in a large sense a multidisciplinary approach. Thus it involves various different skills, which are usually available within an organization. From the conception of an idea to its final design finalization to its execution it involves several stages and these stages preferably called as iterations. The product development is a complex process and essentially involves many stages.

The main stages are:

5.1.1 Idea generation

The new product development process starts with the search for ideas. The market scope and product objective help define the idea. New product ideas can come form many sources: customers, scientists, competitors, employees, channel members and top management of the company. But according to the marketing concept customer needs and wants are the logical place to start the search for ideas. The highest percentage of ideas for new industrial products originate with customers[14]. Thus listening to the customer and incorporating his feedback of existing product can also lead to new idea generation. Also studying the competitors products has been good source of new product ideas.

5.1.2 Idea screening

Basic ideas generated in the first process are incorporated in three groups: promising ideas, marginal ideas, and rejects. As the new-product ideas moves through development, the estimates of the product's overall probability of success, is done using the following formula:

Overall probability of success	=	Probability of technical completion	X	Probability of commercialization given technical completion	X	Probability of economic success given commercialization

With this formula the inputs are the product ideas, the target market , and the competition, and roughly estimates of market size, product price, development time and costs, manufacturing costs, and rate of return. At screening stage the overall probability of success is calculated and if this probability is high enough then development is continued [16].

5.1.3 Concept development and screening

Attractive ideas screened in the above process must be defined into testable product concepts. A product idea is a possible product that might be offered to the market. A product concept is a elaborated version of the idea expressed in meaningful consumer terms.

5.2 Concept development

A product idea can be turned into several concepts. This is generally decided by answers to a series of questions;

1.who will use this product (end user)?

2.What primary benefit should this product provide (profit to customer)?

3.When will people consume it (consumption patterns or user characteristics)?

Using these questions, several concepts can be formed. Each concept represents a category concept that defines the product's competition. Now using the major dimensions defined one has to create the product-positioning map for concept.

Next, the product concept has to be turned into a brand concept, using the brand position map.

a. Concept testing

Concept testing involves presenting the product concept to appropriate target consumers and getting their reactions. The concepts can be presented symbolically or

physically. However, the more the tested concept resembles the final product or experiences, the more dependable concept testing is.

b. *Conjoint analysis*

Consumer preferences for alternative product concepts can be measured through conjoint analysis, a method for deriving the utility values that consumers attach to varying levels of a product's attributes. Respondents are shown different hypothetical offers formed by combining varying levels of the attributes, then asked to rank the various offers.

After testing, a preliminary marketing-strategy plan for introducing the new product into the market. The plan consists of three parts. The first part describes the target market's size, structure, and behavior; the planned product positioning and sales, market share and profit goals sought in the first few years. The second part outlines the planned price, distribution strategy, and marketing budget for first year. The third part describes the long- run sales and profit goals and marketing-mix strategy over time.

After developing the product concept and marketing strategy, it can evaluate the proposal's business attractiveness. Then the product concept can move into the product development stage.

5.1.4 Product development

In this stage the product concept that has been screened is turned into a actual prototype incorporating the customer inputs. The job of translating target customer requirements into a working prototype is helped by a set of methods known as *quality function deployment* (QFD). The methodology turns them into a list of engineering attributes (CAs) generated by market research and turns them into a list of engineering attributes (EAs) that the engineers can use. The methodology permits measuring the trade-offs and costs of providing the customer requirements. A major contribution of QFD is that it improves communication between marketers, engineers, and the manufacturing people.

Then one or more physical versions of the product concept; its goal is to find a prototype that consumers see as embodying the key attributes described in the product-concept statement, that performs safely under normal use and conditions, and that can be produced within the constraints imposed by time and money.

The thing that makes QFD unique is that the primary focus is the customer requirements. The process is driven by what the customer wants, not by innovations in technology [17]. Consequently, more effort is involved getting the information necessary for determining what the customer truly wants. Success in determining customer requirements is directly related to success in the marketplace. This is critical to the whole process. Once a product is defined, QFD enables the design phase to focus on the key customer requirements, those elements that are defined as being very important to the customer. By addressing these elements the design phase is shortened to focus on items that the customers really wants. By concentrating efforts, less time will be spent on redesign and modifications.

On the left side are the customer requirements, what the customer wants in the product. This information is gathered from various sources and fed into this matrix.

The top of the matrix shows the manufacturer's requirements, what the manufacturer does to ensure the consistency of products. These can be items that are measured by the manufacturer or are specified from suppliers.

The right side of the matrix illustrates the planning matrix. This is where the importance rating, the competitive analysis, the target value, the amount of scale up necessary, and the sales points are listed. From this information, a planning weight will be calculated. This planning weight will help the team focus on the items that will yield the greatest potential for success in the marketplace.

The peak of the matrix is the manufacturer's requirements. This is where trade-offs are identified. By identifying these early on product development people can narrow their development efforts, thus speeding up the development cycle.

The body of the matrix is where the relationships are categorized. This is where customer requirements are translated into manufacturer's terms. It is also where the interactions between relationships are identified so that the synergistic effect is seen.

The bottom is the prioritized manufacturer's requirements. This identifies the requirements that are most critical for success as well as the degree of technical difficulty to achieve. All the matrices will be comprised of these fundamental features.

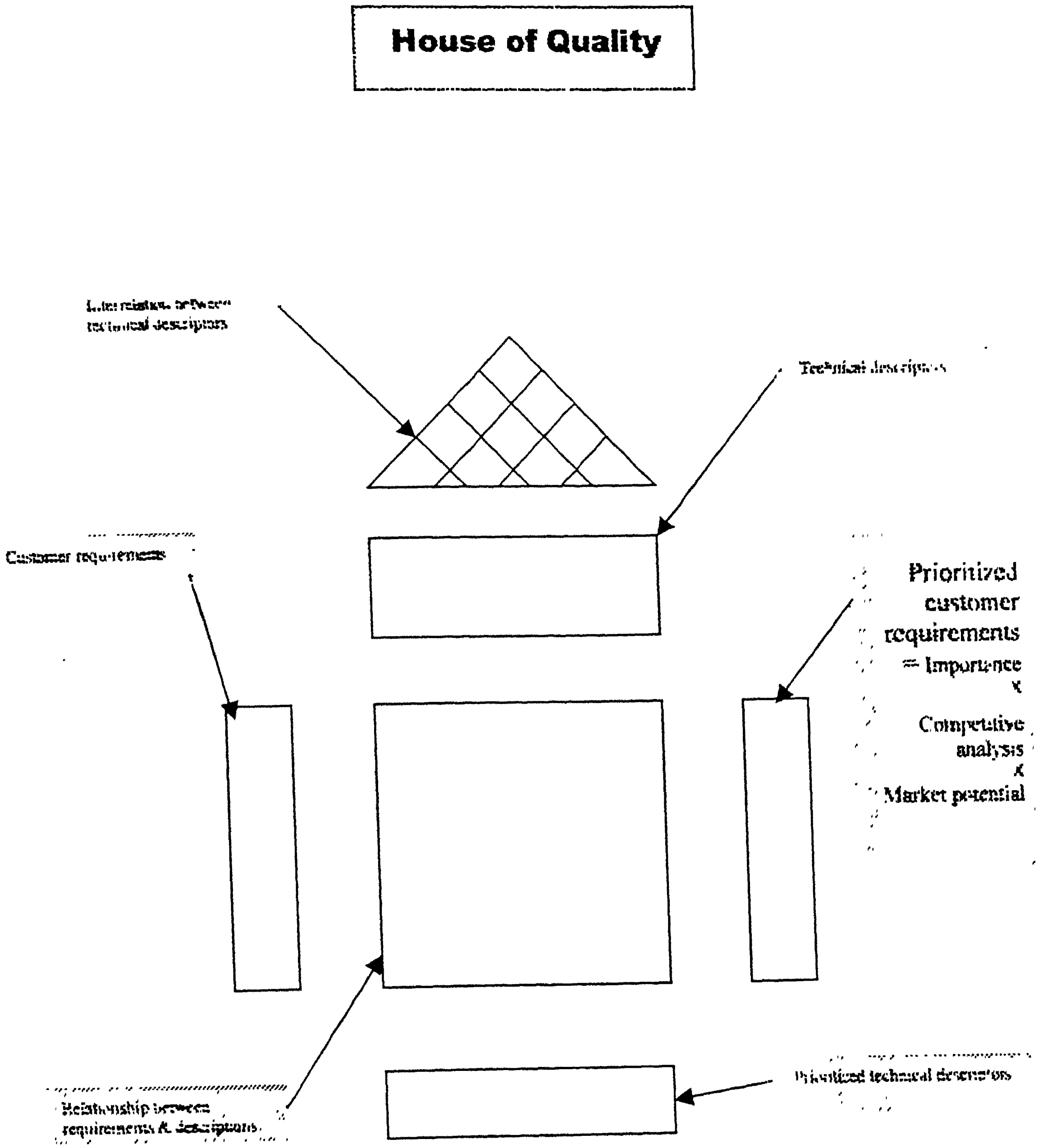


Figure 5.1 A basic QFD matrix showing the various components [18].

5.2 Consumer Survey and Result

As per the primary requirement of the QFD the end user group was identified and customer response was obtained on the basis of focus groups, in-depth interviews of the expert user and formal consumer survey done in Kanpur and Delhi, where the awareness level of the problem was high and thus consumer attributes generated were likely to be closer to the actual design attributes required.

. Consumer survey was conducted based on questionnaire. Total of 117 persons were surveyed and a total of 100 responses were selected for analysis. The highlights of the consumer survey are summarized as below:

5.2.1 Characteristics of the population surveyed

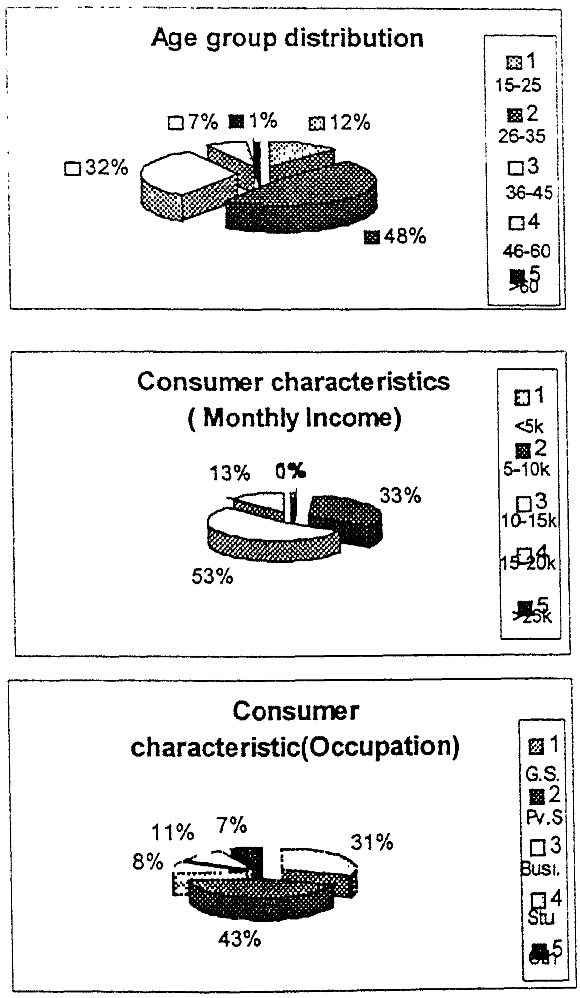


Figure 5.2 Graphs showing the composition and characteristic of the surveyed population.

1. Main consumer group owning two-wheelers falls in the age group of 26-35.

2. The owners have typically household monthly income in the range of 10-15 thousand per month.

3. Majority of the population either work in government sector or in private sector.

5.2.2 Findings of the survey: -

1. Majority of the respondents fell in the 25-35 age groups, which is the target group.

2. Majority of the commuters suffer from bad air quality during commuting and exhibit symptoms, which are indicative of the effects of pollution.

1. Majority of the respondents had their monthly income in the range 10-15 thousand per month.

2. Majority of the respondents were either employed in private sector or government services.

3. Majority of the travelers used to commute around 1-2 hours daily.

4. Majority of the target group ended up commuting 250 or more days per year.

5. Majority of the users are office goers.

6. There is a very strong awareness about the pollution.

7. Available pollution control masks enjoy very little confidence among the commuters.

8. Majority of the consumers were prepared to spend 300-400 and beyond for an effective solution to the problem.

9. Majority of the surveyed population are unhappy with helmets due to poor air circulation and their unsuitability to the Indian conditions.

12. Majority of the surveyed population used handkerchief or no protection against pollution.

Figure 5.3 Customer preference for handkerchief instead of pollution masks.

5.3 Generation of Consumer Attributes (CAs)

Consumer attributes were largely generated by in-depth interviews with experts, end users and focus group discussion. The focus group consisted of people who constituted the first target group; the office goers. The information given out by the focus group was captured in their words and it was grouped later into desirable qualities. The primary attributes were then redirected and after discussions with expert users were crystallized into secondary and tertiary attributes. Primary attributes represent an overall customer concern. After determination of attributes their relative importance was assessed at the user level and also at the expert level and a system of weights was assigned so as to assist in decision-making system.

Table 5.1 *Consumers attributes(CAs) generated and their weights:*

Primary	**Secondary**	**Tertiary**	**Relative Importance** (out of a scale of 10; 5= high ,1 = low)
Economical	Affordable to income group 10-15 thousand per month	*Total Cost* between Rs 300-500 .	3
	Low maintenance cost and low per day usage cost.	Less number of *moving parts.*	3
		Low filter cost	4
Ease of operation and use	Device be less cumbersome to carry	*Easy attachment* and *detachment* with full faced helmet	2
	Device be small in size and low in weight	*Filter change easy*	3
		Less than 100 gm in *weight* and *single touch operation*	1

Effective	Provide stream of clean air	Provide *relief during intersection stoppages*	5
	Effective and useful in hot summer.	*Enough air circulation*	5
		Significant decrease in pollutant (SO2, NOX, SPM, CO)	4

5.3 Generation of the Technical attributes: -

For this the target customer group's location related data analysis along with the survey of technical literature was done to come up with trends and features essential for the determination and development of the technical attributes.

5.3.1 Data analysis of environmental factors: -

From the focus group studies one of the key areas identified as per the discomfort faced by the consumer was the problem faced at the intersections. To understand the problem faced, the ambient air quality data at ITO intersection was analysed. This data is generated as part of National Ambient Air Quality Survey conducted by CPCB (Central Pollution Control Board).

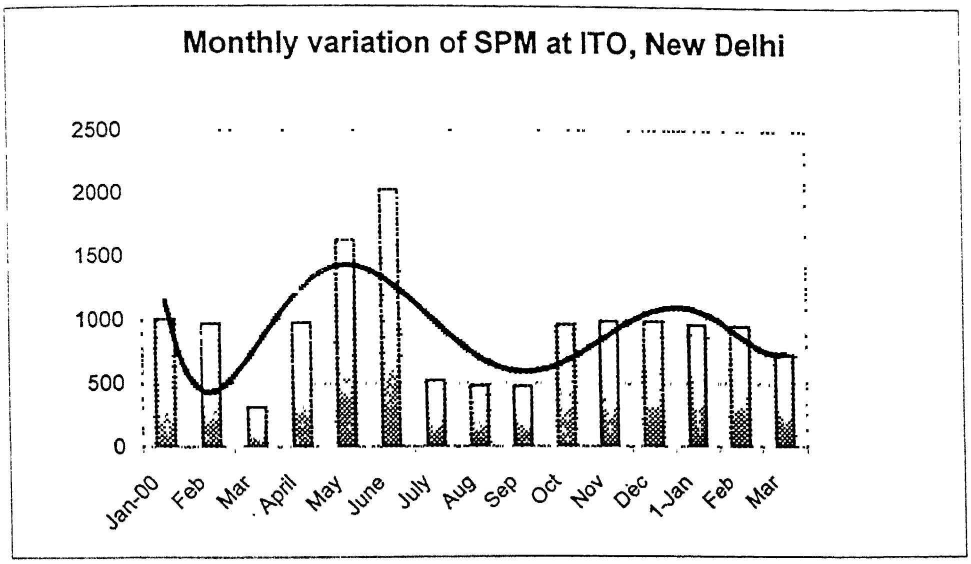
Table 5.2 The standard values are of the major parameters of the air quality(as per CPCB norms) .

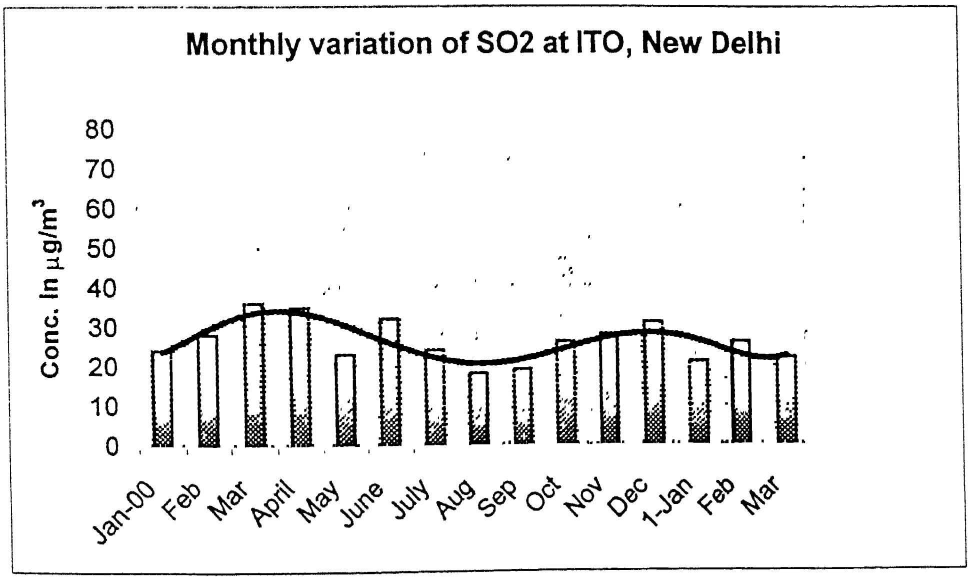
Pollution Level	**Monthly Mean Concentration Range ($\mu g/m^3$)**					
	Industrial			Residential		
	SO_2 & NO_2	SPM	PM10	SO_2 & NO_2	SPM	PM10
Low (L)	0-40	0-180	0-60	0-30	0-70	0-30
Moderate (M)	40-80	180-360	60-120	30-60	70-140	30-60
High (H)	80-120	360-540	120-180	60-90	140-210	60-90

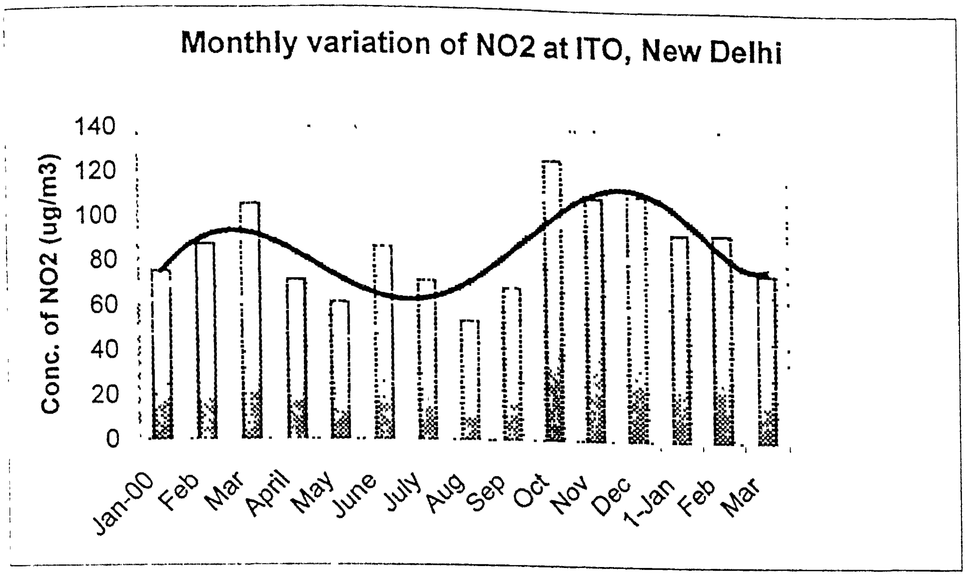
Critical (C)	>120	>540	>180	>90	>210	>90

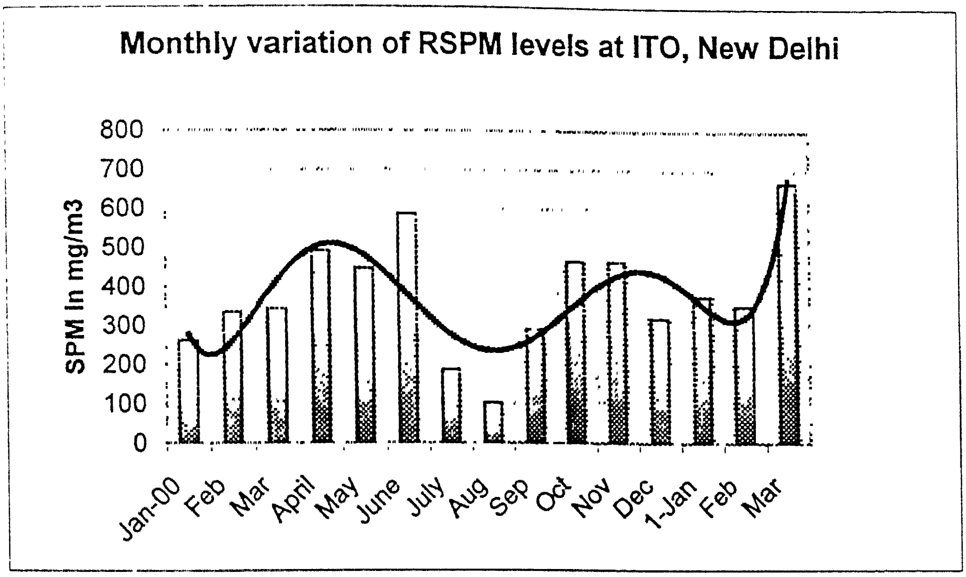
* The standard value of CO is taken as 2000 μg/m^3 measured as 8 hourly average.

Accordingly the data is plotted and the trends observed are shown using sixth degree polynomial curve.









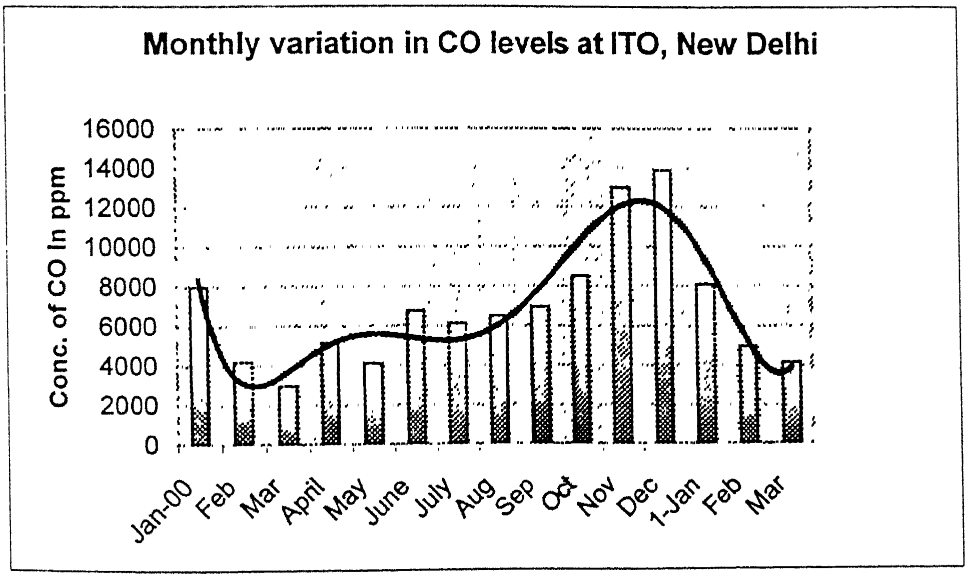


Figure 5.4 Monthly variations in the air quality parameters at ITO intersection, New

5.3.2 Trends in Air Quality:

1. General

(a) The air quality as defined by the parameters in terms of the five parameters more or less show a dramatic decrease in the summer months (April to June) and winter months (Nov to Dec).

(b) The pollution level at the ITO crossing is high to critical and in some months it is more than critical. This shows that the increasingly vehicle density coupled with low ventilation coefficient at the intersection makes it the zone of acute effects.

(c) The air quality in the monsoon months is good as compared to other months due to the cleansing effect of the rains.

2. Specific to a pollutant

(a) SPM as recorded shows very high peak in May and June months , which is way above the 200 mg/m3 value that is taken as standard. However the very high value recorded is exaggerated due to high ratio of wind blown dust particles. However the value recorded in Nov and Dec Months is closer to the actual value produced by the vehicular pollution. Still the SPM levels are way much higher and cause of concern.

(b) SO2 levels are low to moderate throughout the year and as such are not critical levels for air quality.

(c) NO2 levels are clearly are more than critical in the summer and winter months and moderate to high in the remaining months. It is due to high incidence and popularity of the diesel vehicle in the capital.

(d) RSPM levels are very high in summer months and in winter months. Their high values in the winter months are alarming as due to inversion condition they cause a steep fall in both physical as well as visual air quality.

(e) Often called the silent murderer, because of it being passed virtually undetected by the sensory organs of the body, its very high values are a cause of concern especially in Nov to Jan periods.

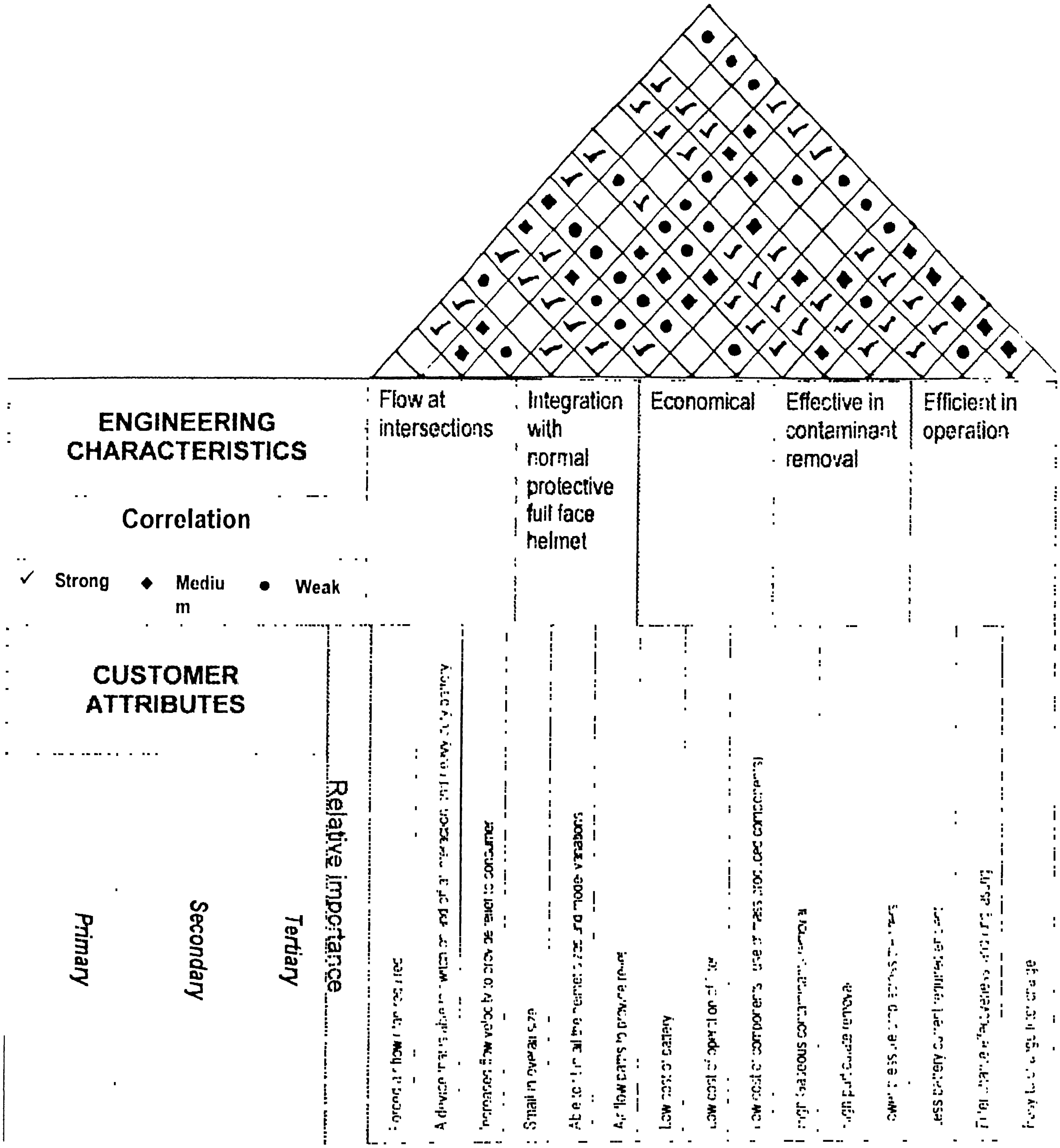
Thus we can now confirm what was given as the input by the consumer that, intersections are one of the most critical places. Whatever might be the solution of the problem must take into account the general high level of pollution at the intersections.

After analysing this data and the other technical consideration to be taken into account the following technical attributes were came up with along with their subattributes.

Table 5.3 *Technical attributes generated*

Primary Attributes	**Secondary Attributes**
Flow at intersections	Forced air flow (fan required)
	A device that is able to switch on and off at interaction and heavy duty battery
	Increased flow velocity to provide relief to consumer
Economical	Low cost of battery
	Low cost of operation of filter
	Low cost of components (use of mass produced components
Integration with normal protective full face helmet	Small in overall size
	Able to fit in all the helmet sizes and model variations
	Air flow paths to provide relief
Effective in contaminant removal	High Gaseous contaminants removal
	High particulate removal
	Lower pressure drop across the filters
Efficient in operation	Less battery/current required/efficient
	Filter charge effectiveness and long lasting
	Easy to change filter charge

Table 5.4 House of Quality for Personalized Air Purifier System



Effective			Economical			Ease of operation and use			
Provide stream of clean air	Effective and useful in hot summer.		Affordable to income group 10-15	Low maintenance cost per day usage cost.		Device be less cumbersome to carry	Device be small in size and low in weight		
Provide relief during [illegible]	[illegible] air circulation	Significant decrease in pollutant (SO2, NOX SPM, CO)	Low filter cost.	Total Cost between Rs 300-500	Less number of moving	Filter change easy	Easy attachment and detachment with full faced helmet	Less than 100 gm in weight and single touch operation	Technical Difficulty (in scale of 1-5)
			✓			✓			5
		✓	✓	◆		●			2
				✓				◆	4
			●						5
✓	✓		●						5
		✓	◆						4
		✓	✓	✓			◆		2
			✓	✓					4
				✓					4
◆	◆								3
				●	●		✓		3
◆				●	●		✓	✓	4
✓	✓								5
◆					●				1
✓	✓	●		●			●	●	1

Imputed Importance (%) (a total 100%)	[illegible]	[illegible]	[illegible]	5	[illegible]	5	6	7	6	8	8	5	4	[illegible]	[illegible]	[illegible]

5.4 Summary of Iterations

As per the house of quality matrix three iteration of the basic design were performed and their summary is given in this section. The basic innovation loop was followed (fig.5.3). The first exploratory prototype was generated using the respirator selection provided by NIOSH (fig. 5.4).

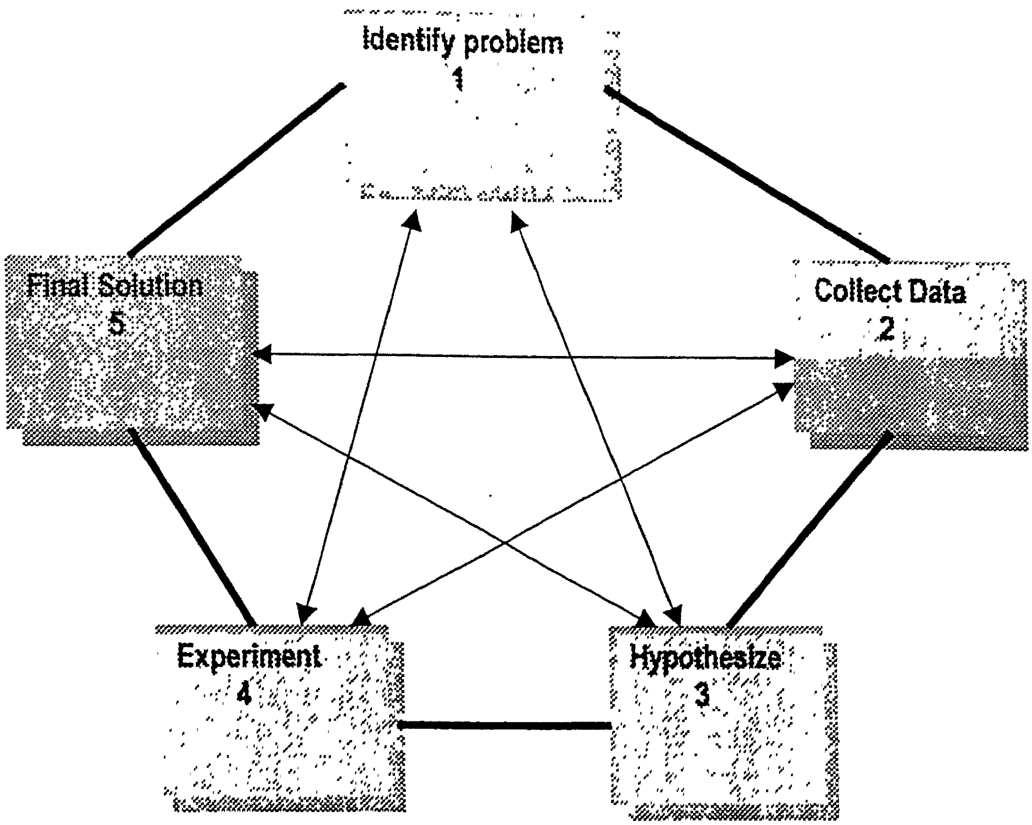
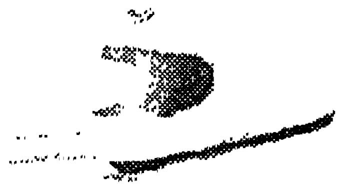


Figure 5.5a The stages of the product design process followed in iterations [17].

5.4.1 First Iteration: -

This prototype was in the form of exploratory prototyping. The arrangement was done on the basis of information gathered from technical resources and limited personal experience(fig 5.5b). This was done to get the feel of the problem, and extent of involvement of time and resources required and also the reaction of the end user. After designing the prototype it was explained to end-user. The user input was used as input for house of quality matrix.



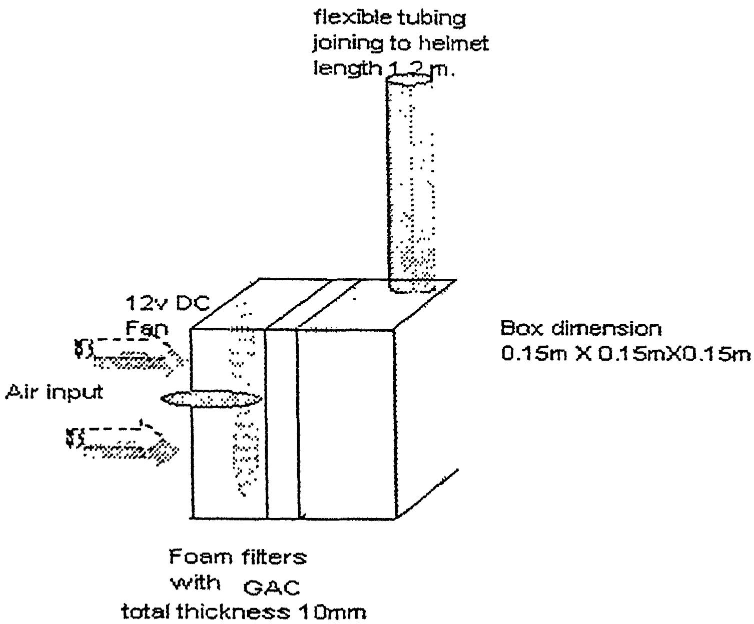


Figure 5.5b Schematic diagram of the first iteration.

5.4.1a Description of the arrangement

Filter unit: -

Normal filter consisting of foam fabrics and ...

Fan 12 v DC fan with very high air flow 200 mm X 200 mmX120mm

Connecting Mechanism (flexible pipe tubing)

Power Source: -

Battery of the vehicle, which has output voltage in the range of 12v-9v.

Component cost of the arrangement: -

800 rupees.

5.4.1b Drawbacks: -

1. System not user friendly. Piping hindering movement and is at best clumsy.
2. Unit is bulky and will consume valuable space on the vehicle.
3. Not very easy to install on motorcycles.
4. Possibility of deposition on the pipe inside, which may come out while shaking thus resulting in shock loading.
5. Possibility of tubing being cut accidentally.
6. Possibility of the development of excess pressure inside the helmet leading to the reverse flow condition.
7. Unit has to be operable on a continuous basis for 1-2 hours.
8. Unit is not able to take into account the natural air velocity during movements.
9. Cost is still high in the range of 600-700 rupees.

5.4.2 Second Iteration

The second iteration was planned with the incorporation of the feedback generated in the first iteration. One of the major drawback was the flexible tubing required in the first arrangement which made the whole arrangement clumsy and not user friendly. On sudden insight it was decided to do away with the flexible tubing. But this necessitated that the system should be miniaturized. Further the system had to have a dimension not in excess of a cube of 5cmX 5cm X 5cm due to vision restriction. Taking into consideration the ' House of quality' approach the arrangement for the second iteration was arrived at (fig 5.6). This arrangement had none of the drawbacks of the previous systems.

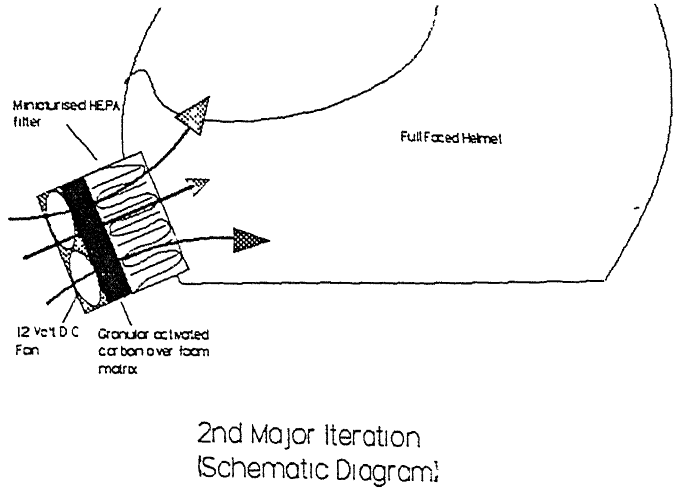


Figure 5.6 Schematic diagram for second iteration.

5.4.2a Description of the arrangements

Filter material used

A miniaturized HEPA (High efficiency particulate arresting filter) was prepared and used. Using HEPA (high efficiency particulate arresting) filter to clear out sub-micron size particulate matter. In this type of filter one force air through a very torturous path so that particulate matter are arrested on the filter .To provide this force we are using a miniaturized high rpm fan. This will also help at traffic crossings and jams where there is no air velocity available to force the air through, thus removing one of the most difficult of problem this will be integrated with the helmet.

The filter used can remove the particulates up to 0.3µm with 99.97% efficiency (fig 5.7).For gaseous contaminants filter made of granular activated carbon deposited over foam filter matrix and held by a adhesive film applied uniformly (fig 5.8). Activated carbon posses the property of adsorbing most of the gaseous pollutant like sulfur dioxide, nitrous oxide and PAHs. In the powdered form its surface area increases and thus it has more active sites for adsorption. It is impregnated in the foam to provide a film like obstruction for the passage of the gases .In the average condition it has got a life of approximately sixth months. After which it can be taken out and replaced by a new one The whole arrangement was with total dimensions of 55mmX55mmX50mm(fig 5.9).

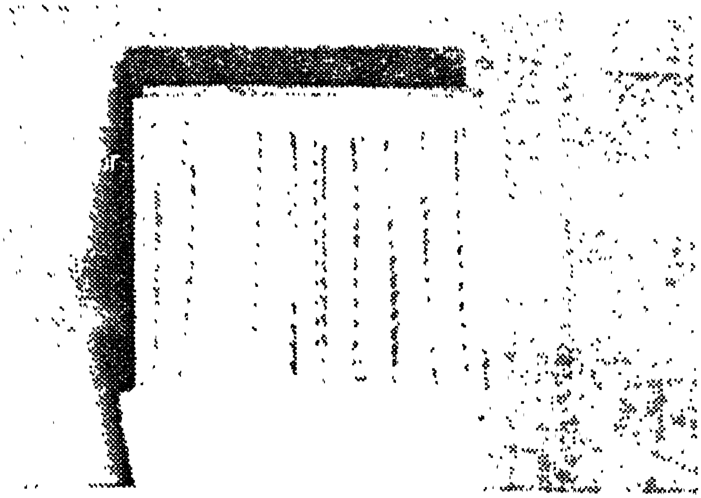


Figure 5.7 Miniaturized HEPA filter

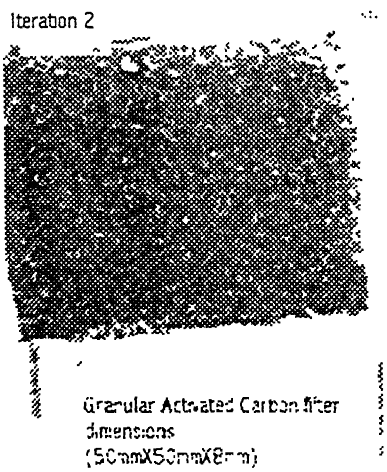


Figure 5.8 Granular activated carbon filter

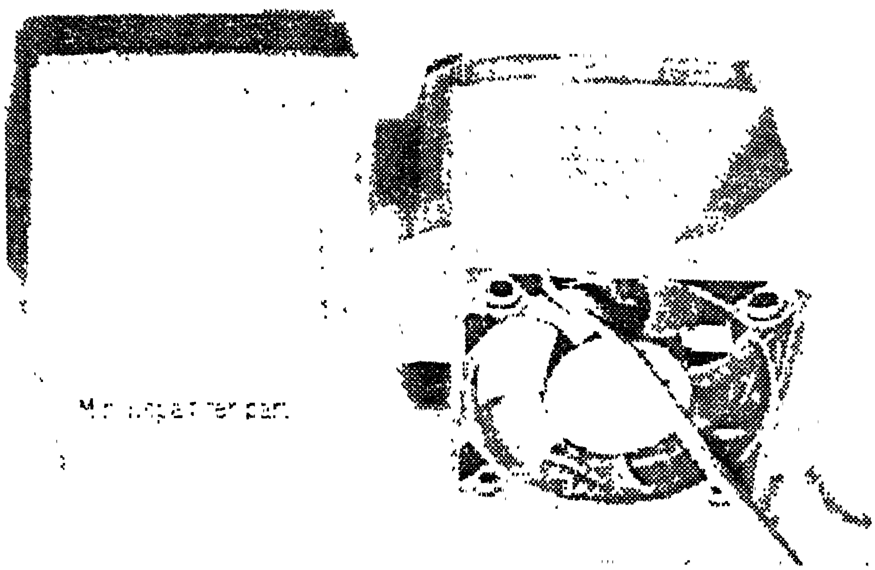


Figure 5.9 Complete filter assembly

Drawbacks of the design:

1. Still bulky and cumbersome to use.
2. Filter replacement not easy for average user as the whole arrangement had to be kept open.
3. High chances of the filter damage during installation, as Mini HEPA filter is susceptible to damage.
4. Lowlife of the filter as the efficiency of the filter is very high.
5. Filter attachment mechanism not very effective for sudden jerks.
6. Cost is higher.
7. Main drawback; the resistance to flow was greater; although efficiency is higher.

   Although the standard DOP test could not be done on it.

5.4.3 Third iterations: -

5.4.3bFilter fabric selection for iteration 3

a) Guidelines followed for selecting the fabric on which activated carbon/activated charcoal was impregnated.

1. The fabric must be offering least resistance to flow.

2. The fabric must be having good particle capture and retention capacity.

3. The fabric should be able to take a good coat of the activated carbon/activated charcoal and retain it over a period of time without a reduction in strength.

4. The fabric should be available at the market at a reasonable price.

5. The fabric should be able to retain the coating in humidity that might be present.

6. The fabric should retain its strength over a long period of time with coating

After a long selection trial a total of six fabrics (fig. 5.10) in the woven category were selected and their flow resistance characteristics were studied using a very sensitive anemometer capable of measuring flow velocity as low as 1 foot per minute with an area of 98.8 sq cm.

Their flow rate variations with respect to coating given indicate that fabric with medium warp/weft ratio and synthetic performed well in terms of having less resistance to flow, consequently low pressure drop across the surface(fig . 5.10b).

(a) C1 (b) C2

(c) C3 (d) C4

(e) C5 (f) C6

Figure 5.10a Fabrics selected for making activated carbon filters

Table 5.5 Filter fabric descriptions

Fabric name	**Description**	**Mesh count** Warp/Weft per cm
C1	A pure polyester cloth with bigger pores	18/28
C2	A pure cotton cloth with cambric weave	30/38
C3	A pure cotton cloth with larger pores	22/34
C4	A pure cotton cloth with larger dia	28/36
C5	80% polyester mixed with 20%cotton cloth	42/48
C6	A 100% polyester cloth reinforced for greater strength.	28/32

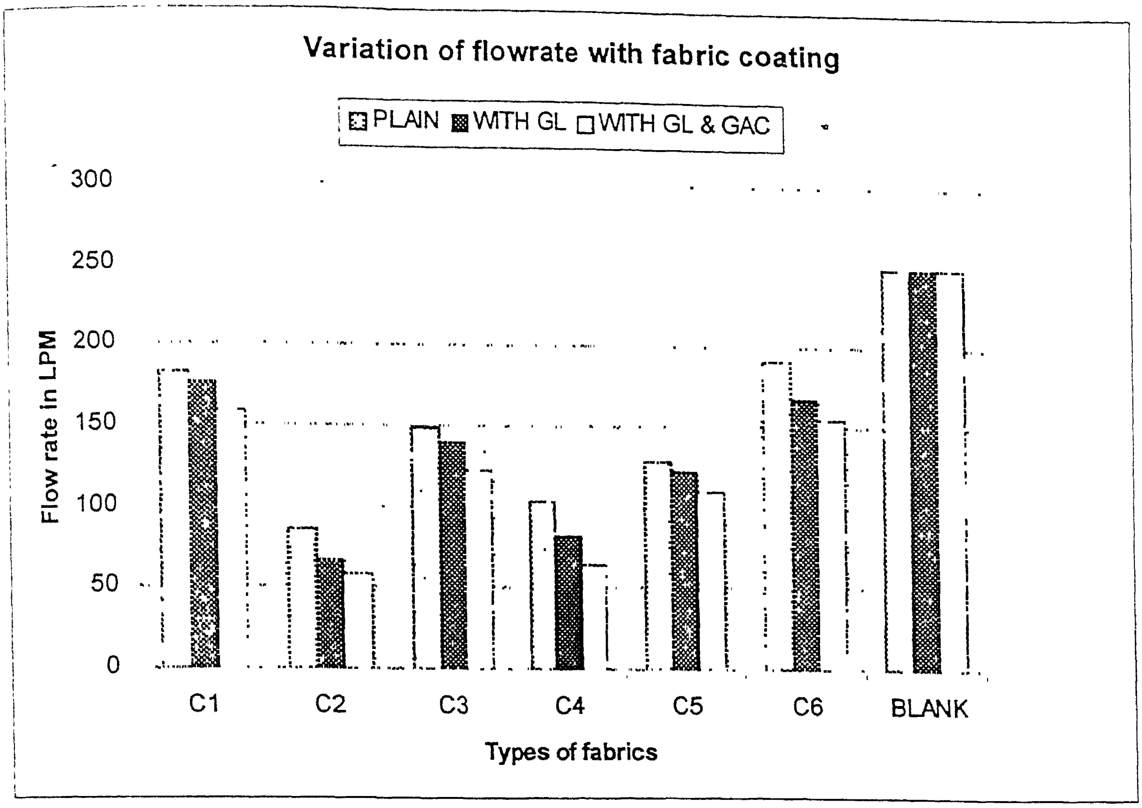


Figure 5.10b Variation of flow rate with different coating

5.4.3c Major variations in coating in iteration 3

Variation 1:

First attempts were made to fix the activated carbon particles over filter fabric and thus achieve a workable surface over which particle capture can take place. The first few attempts used a commercial available synthetic rubber adhesive for fixing the layer of the activated carbon particle. After the coating was over, it was left to dry overnight. This ensured that all the vapors given out by the adhesive film were exhausted. After this the coating was immersed in water for a period of 6 hours To ensure the uniform laying of activated carbon particles different methods were adopted which ranged from;

a. Using brush to lay the adhesive and then apply the activated carbon layer using perforated activated carbon particle dispenser while keeping it within a distance of 10-15 cm. This resulted in non-uniform coating as the concentration of retained activated carbon particle was found to be strongly correlated with the concentration of said adhesive film.

b. In the second approach; just the reverse of the above approach was

activated carbon granules, a layer of activated carbon granules were laid on a leveled foam bed and then the fabric was rolled with a roller while keeping the adhesive film free side up. Again the results were a bit more uniform layer but the layering achieved was not repeatable and a variation of 5-10 % by weight was found.

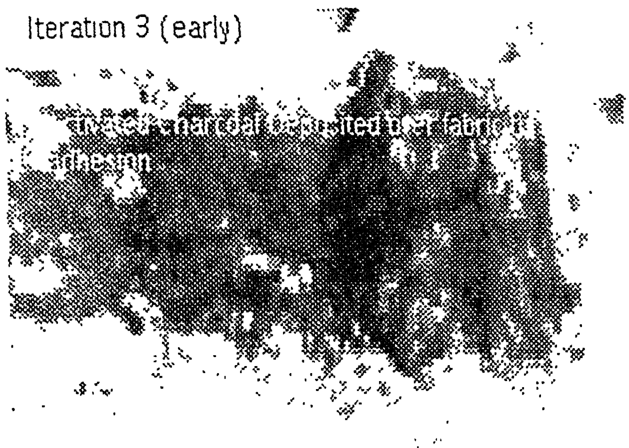


Figure 5.11a Activated charcoal deposited over fabric thorough adhesion

c. The third approach involved included spraying activated carbon and activated charcoal by keeping them in suspension in either commercially available kerosene or petroleum spirit using handheld sprayer. The idea was that the suspension medium would evaporate leaving behind the uniform activated carbon layer. But due to problems of sprayer getting clogged this approach was discarded.

d. After the failure of above approach, just the reverse of the above approach was attempted. The adhesive was diluted using petroleum spirit and sprayed on the layer of the activated carbon and activated charcoal layered over the fabric. The coating achieved was uniform and was retained well over a period of wet and dry cycle but a new problem emerged. The coating had a layer of adhesive on them, which blocked the pores of the activated carbon (fig 5.11a) . This was a serious drawback resulting in reduced area available for adsorption. Thus the results obtained were discarded.

Variation 2:

After the failure of above approaches a fresh method was adopted. Realizing that the velocity through the filter will not be that high and as such one need not use the adhesive to retain the activated charcoal particles, if one can have a highly viscous film over which one can deposit the activated charcoal layer; it would be sufficient. After a search glycerin was chosen as it is highly viscous and the engineering properties(appendix C) approach the desired. After experiments this was found to be an adequate arrangement as it improved particle capture and retention much greatly along with providing a film for attachment of activated charcoal particles (fig 5.11b).

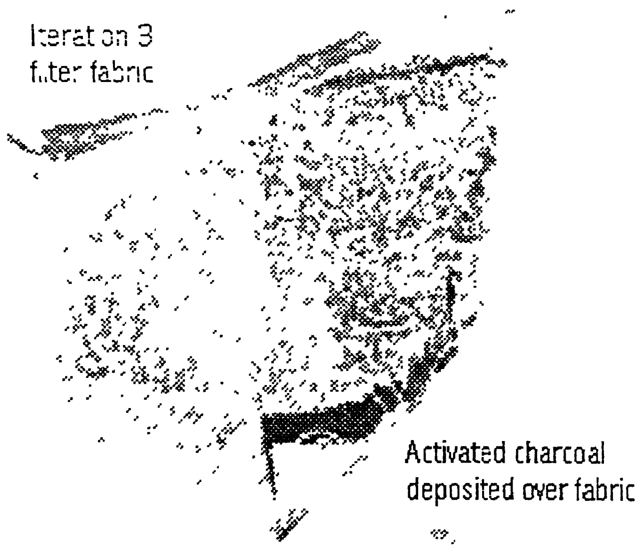


Figure 5.11b Activated charcoal deposited over glycerol coated fabric

However the major drawback of this was the fact that the total amount of activated charcoal was less thus requiring frequent replacements, which will entail high cost of installation and maintenance. But the concept of glycerol coating was retained as the result obtained in particulate capture and retention was excellent. This was tested by capturing the particulate matter using a handy sampler. The sampling site was chosen as 'Naveen Market intersection' due to lots of particulate matter generated by high traffic volume. The sampling was done on a winter day, just after a brief spell of rains so as to rule out particulate matter originating from dust. The fabrics with different coating were photographed using SEM (scanning electron microscope). The photographs clearly show the enhanced particle capture in fabric coated with glycerol (fig 5.13, 5.14, 5.15, 5.16).

Variation 3

In the third variation a entirely fresh approach was tried. Using the fact that photocopier toner used is also a sort of carbon, photocopier was used as depositor of activated charcoal on the fabric

. The process is described as a series of steps

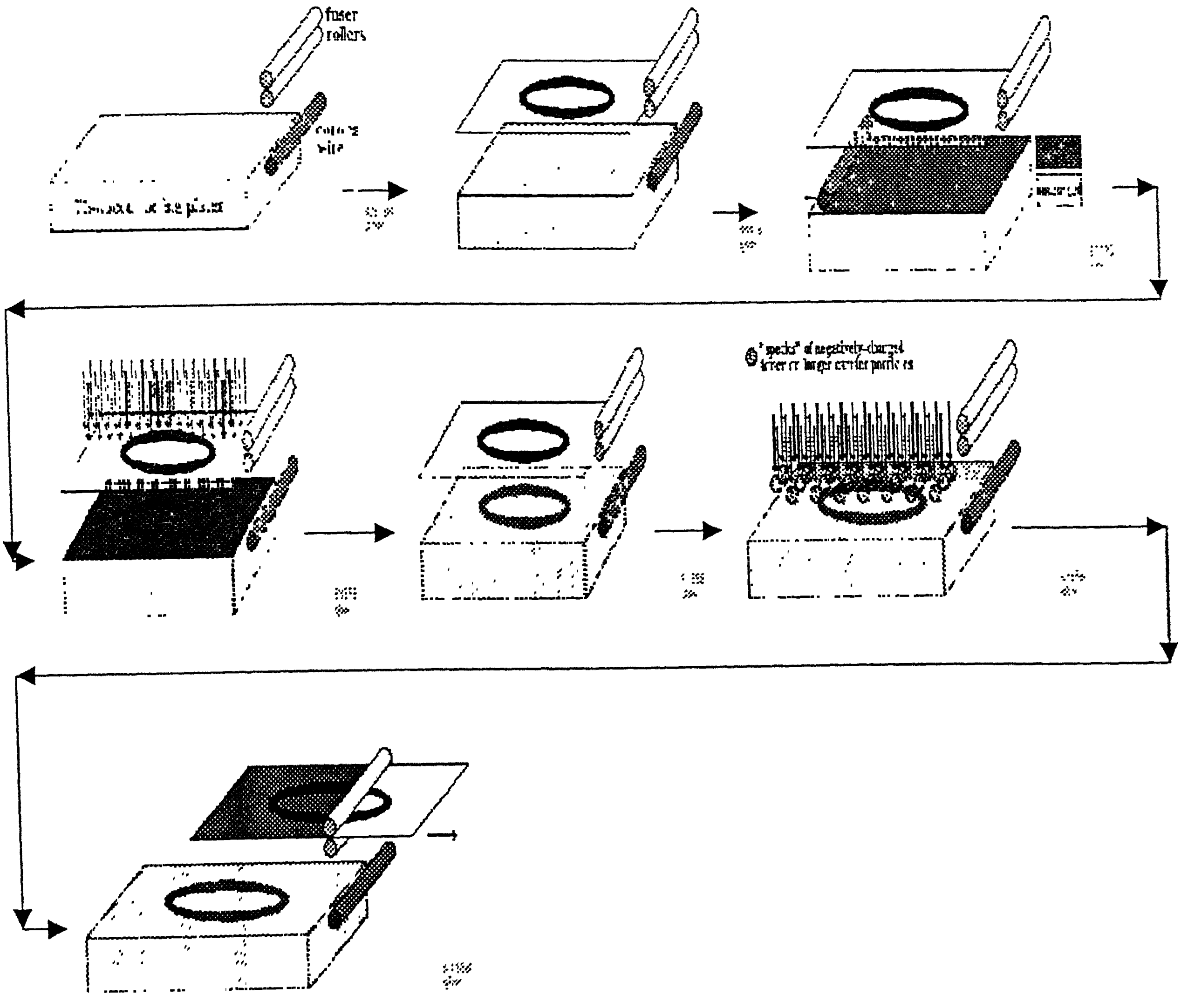


Figure 5.12 steps showing the methodology adopted in depositing activated charcoal over the fabric using commonly available photocopier.

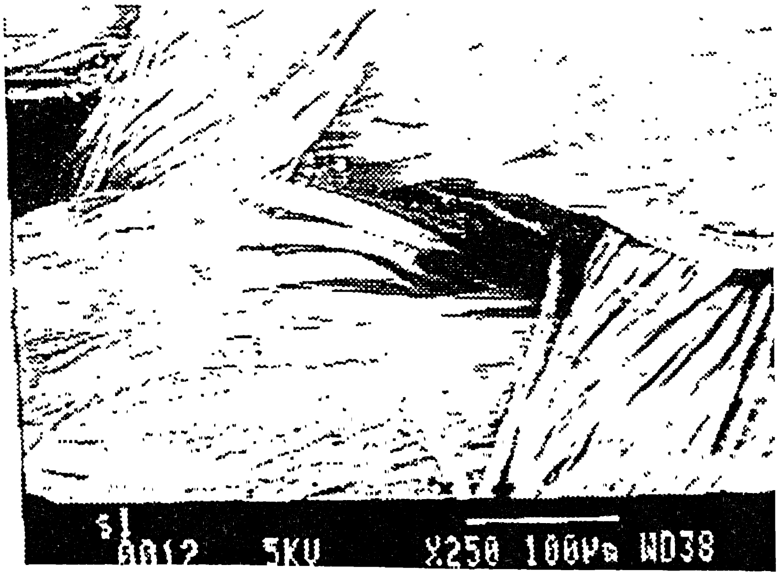


Figure 5.13 Cotton fabric C2 plain without coating after a hour of exposure

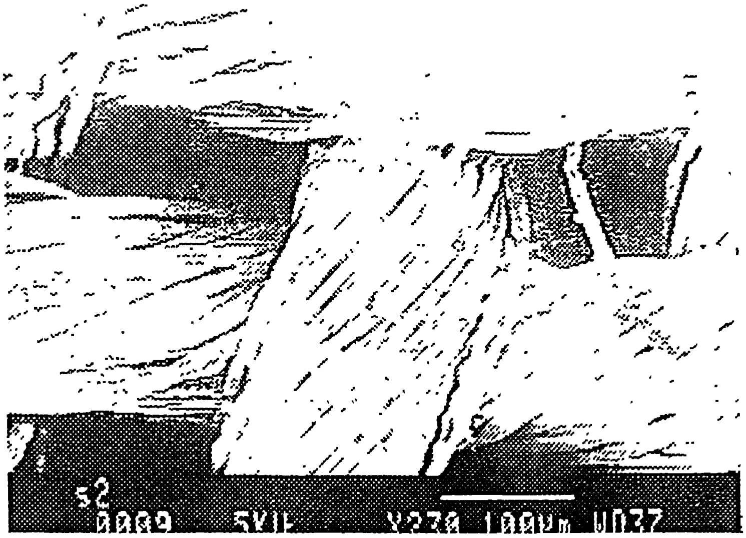


Figure 5.14 Polyester fabric without coating after an hour of exposure

Figure 5.15 Cotton fabric C4 coated with glycerol after one hour of exposure

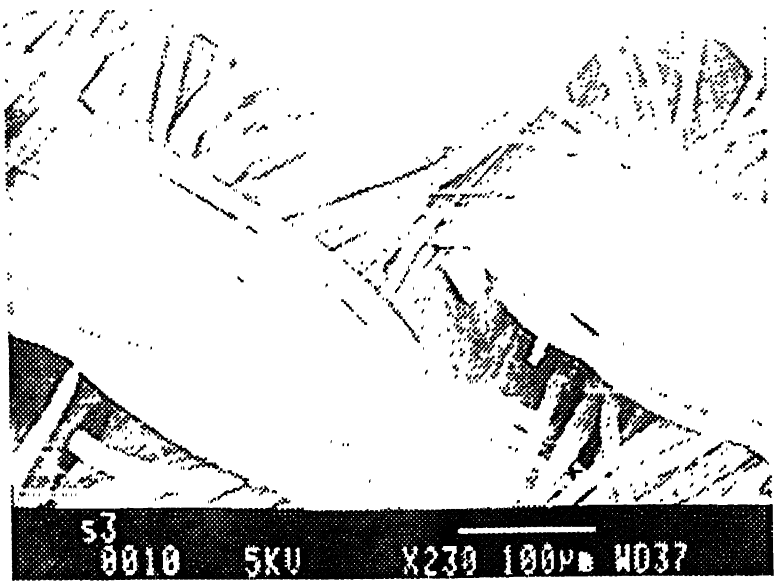


Figure 5.16 Polyester fabric C5 coated with glycerol after one hour of exposure

Chapter 6
FINAL DESIGN

6.1 Development of design

Design is the conscious, human process of planning physical things that display a new form in response to some predetermined need. Further, this activity implies a creative, purposeful, systematic, innovative, and analytical approach to a problem.

In the act of designing, primary consideration must be given to the needs of the user, involving the special functional, material, and visual requirements of the problem. These human factor needs translate as a series of subsets pertaining to purpose or use, physical substance, and appearance. Human factors are important in designing. The obvious aim is to create a product that not only works and is durable but also looks good. Good design demands this attention several aspect of the problem at hand.

A good design must possess both function and form. A product must fit the purpose of need for which it is intended. In other words, the well-designed article works as it is supposed to work. It functions. It is usable. one must never allow aesthetics to interfere with function. One must let function guide the design effort, but the effect must also be visually appealing to the senses. Thus a judicious balance between function and form was sought to be achieved by applying design principals along with the generated feedback included from the iterations.

6.2. Design principals

Although it is virtually impossible to break a design into components, or to speak of the method of organization that give it unity, one can generalize some of the basic design principals that were followed in creating the design. Four design principals were followed in creating the form.

6.2.1 Unity and Variety

Unity and balance are closely related, for within a design there must be a sense of belongings or similarities (unity) among the components parts to achieve order and wholeness. Concurrently, there must be sufficient diversity or contrast (variety) among

the parts to display interest and to relieve monotony. Unity and variety contribute to the means by which the overall effect of a design is analyzed. Unity is harmony, similarity, agreement, repetition, affirmation, and continuity. If a design has unity, it means that everything is woven together according to some well-developed scheme. Variety provides the aesthetic contrast. Rhythm is the flow or movement of the viewing eye as controlled by the repetition of either similar or varying elements, as is therefore closely related to unity and variety.

6.2.2 Balance and Proportion

Balance and proportions are two other principals that were used in the designing. Balance is the quality of equilibrium achieved and sustained through the proper proportioning of the parts of any whole. Ratios of approximately 1:3 or 2:3 are generally considered visually good. In this design both these ratios are used consciously. In the design, proportion is one of th most effective means of creating unity among the various components. The use of proportionate elements- whether of lines, dimensions, areas, colors or textures- help to establish a feeling of fullness and unity, binding all elements together so tightly that removing or altering a single element would disturb the whole design.

Balance is related to proportion in that it is not only a biological necessity in people's makeup but also something we look for in all visual objects. Balance that can be seen in an object is known as optical balance. When the two halves of an object are exactly alike on either side of an axis, the relation is known as formal symmetry. However a design can also be symmetrical when organized radially around a center point.

6.3 Design development

Sensitive, well-designed objects are never achieved by memorizing a long list of design principals and a second list of rules or generalizations regarding their proper application. One never sets out to create well- proportioned, well balanced products. Instead, one embark on the design mission with open, creative minds, searching for form, experimenting with space combinations, sketching possible contours, and seeking solutions that reflect a good organization of elements. Experience, practice, study and intuition, and reflection leads to the ability to discriminate among sensitive and awkward forms. When this feeling of 'rightness' about an object is present, automatically the

objects looks as though all the parts belong together. The absence of this feeling of rightness causes visual tension, or the sense of strained, pulling forces in a composition.

After the main engineering design criteria were taken down as a list of environmental and engineering factors that have to taken into account i.e. the function part was taken care of it was now necessary to take care of the form part. Applying the design principals discussed before, to come up with a design with a balanced function and form. This development is described in a series of sketches, as text is a poor substitute for pictures (fig 6.2, fig 6.2a, fig. 6.2b, fig. 2c, fig. 2d, fig. 2e).

. After the design reached some sort of stable equilibrium, the graph and pencil approach was abandoned and the figure was transformed into a wireframe model in a CAD software(fig 6.3). The software used was I-DEAS for its complete range of solution from drafting to creation of stereo lithography files. Also it has the facility for checking mechanisms and engineering analysis for the parts. After creating the solid model in I-DEAS (fig 6.4, fig 6.5, fig. 6.6, fig. 6.7), files were exported as stereo lithography files which are the standard format files for rapid prototyping. Rapid prototyping is a new term used to denote the quick transformation of the CAD models into solid physical objects and not merely 3-D drawings. Stereolithography was developed by 3D Systems, Inc. This process combines the technologies of computers, lasers, optical scanning, and photochemistry by taking advantage of photopolymers that change from liquid to solid when exposed to ultraviolet light. The patented StereoLithography Apparatus (SLA) converts 3-D computer image data into thousands of layers. Here *QuickSlice pro6* was used for creating slice. A laser beam then traces a single layer onto the surface of a vat of liquid polymer which are joined together with the previously layered surface using ultraviolet light which causes polymer to harden at that point. The process continues until the complete 3-D model is built, one layer at a time, from the bottom up. Typical layer thickness is from 0.076 to 0.381 mm. After final layer it undergoes a final curing with an intense ultraviolet light source. The machine used was FDM (fused deposition modeling) by Stratasys, Inc. The entire process is described in the following flow chart(fig 6.1).

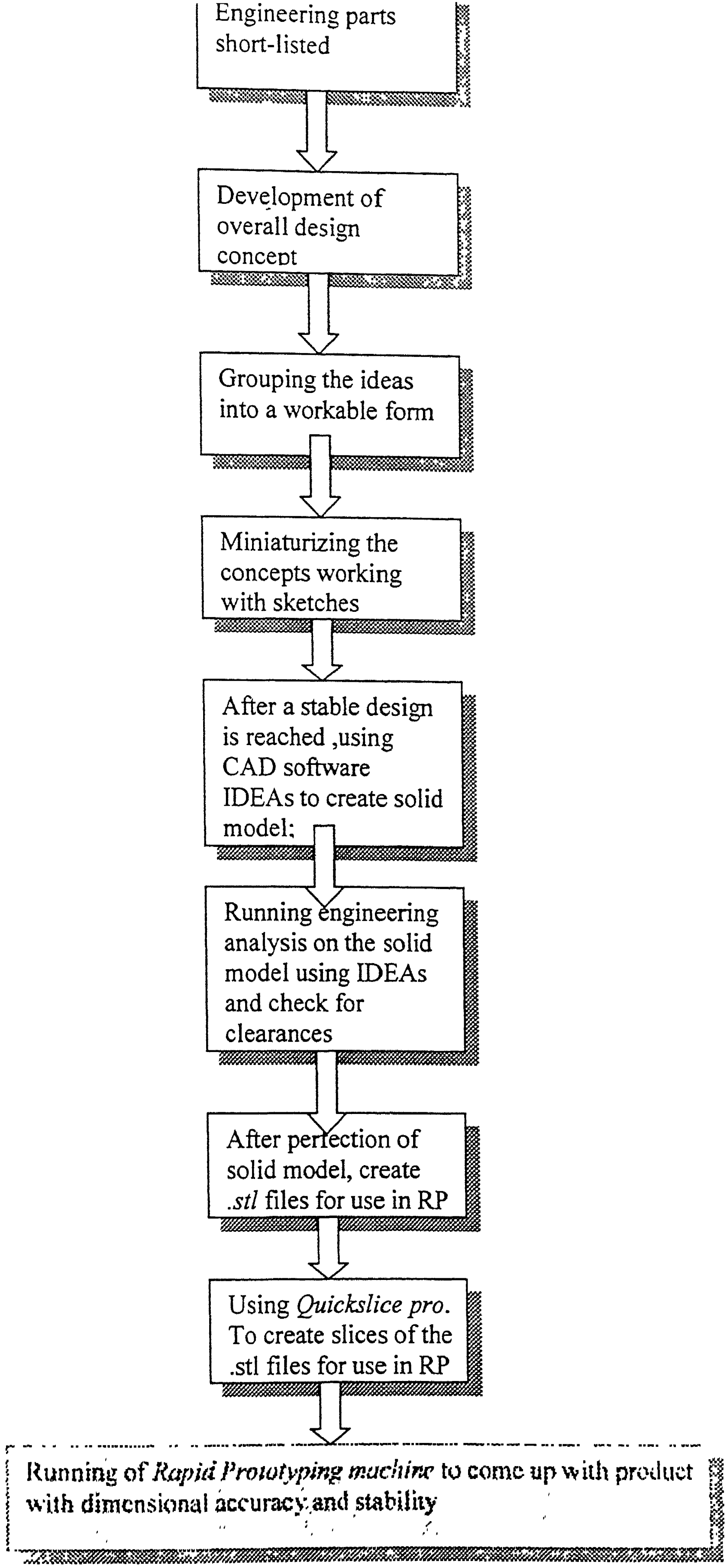


Figure 6.1 Flow chart showing the steps in the design process

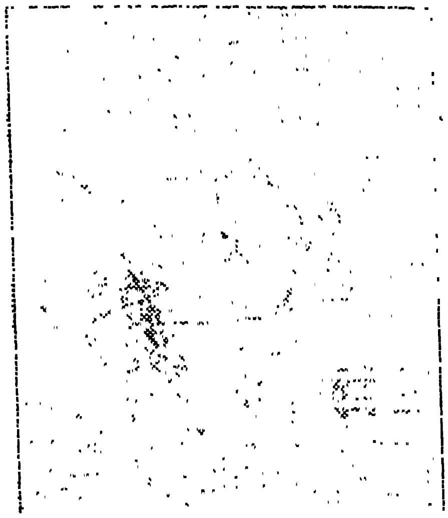


Figure 6.2 Overall concept of the design sketch it has none of the functionality but describes the basic concept.

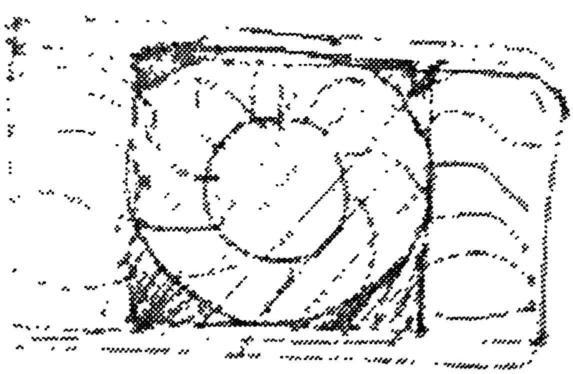


Figure 6.2a The front view in early sketches

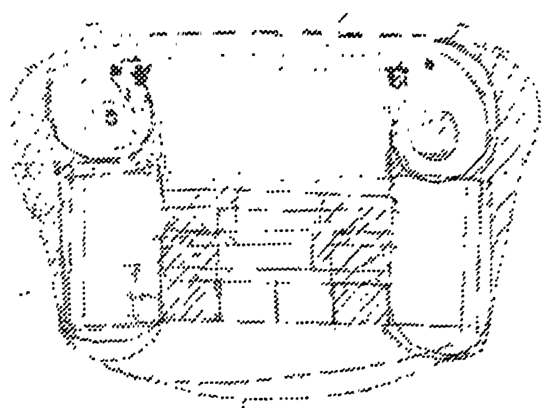


Figure 6.2b The top sectional view of the early sketch

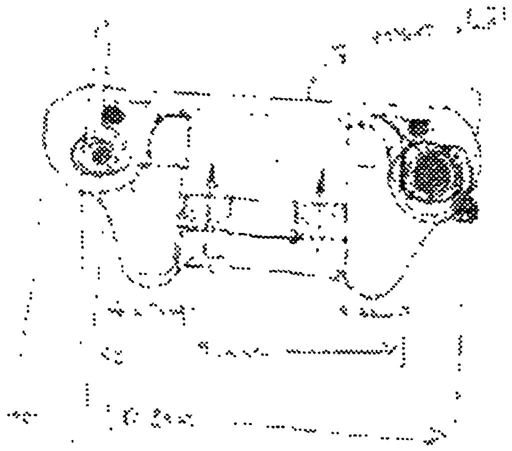


Figure 6.2c The functional parts description with dimension from a early sketch

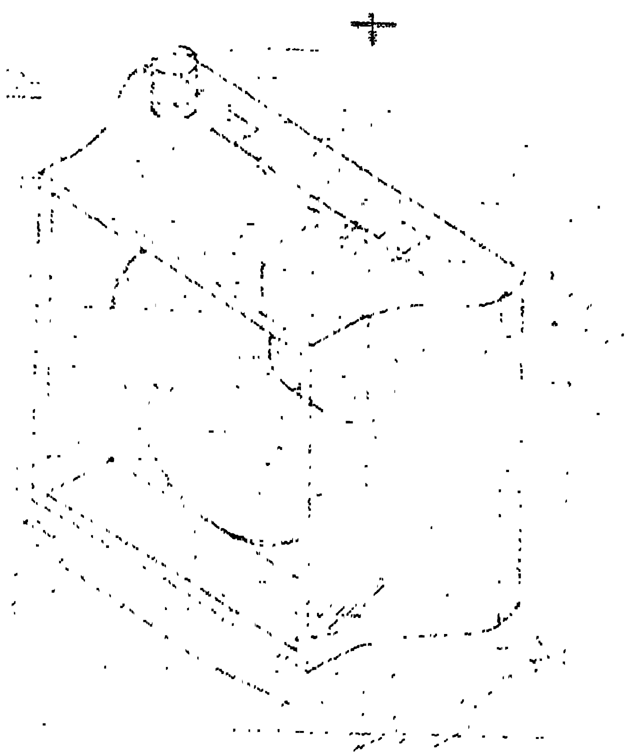


Figure 6.2d functional sketch showing the details and dimension

Figure 6.2e Sketch showing a detailed cross-sectional view with parts description

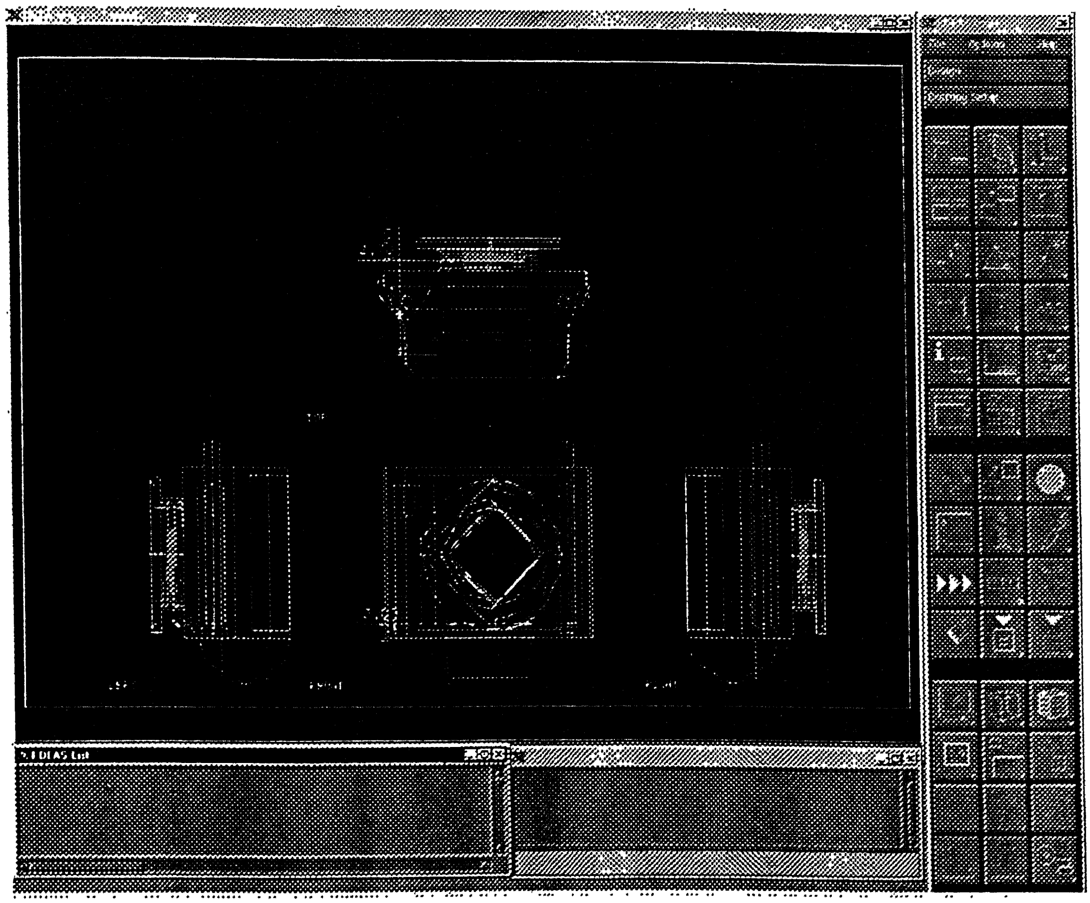


Figure 6.3 I-DEAS output of the wireframe model showing all views.

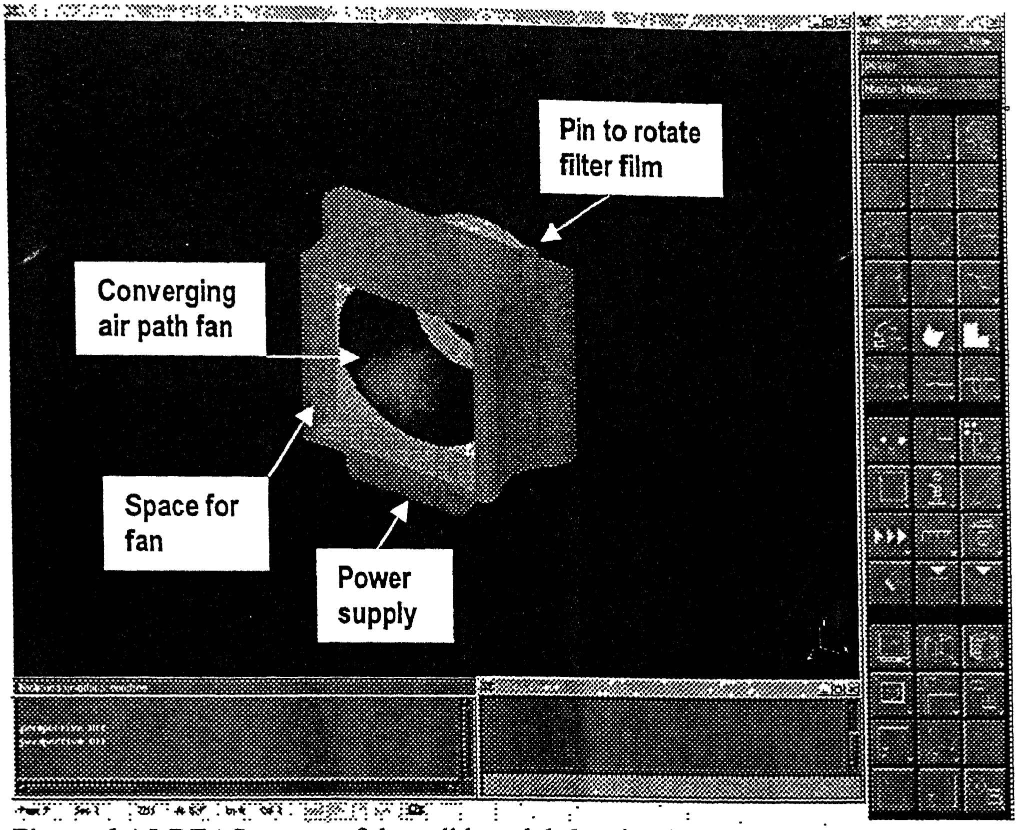


Figure 6.4 I-DEAS output of the solid model showing isometric view

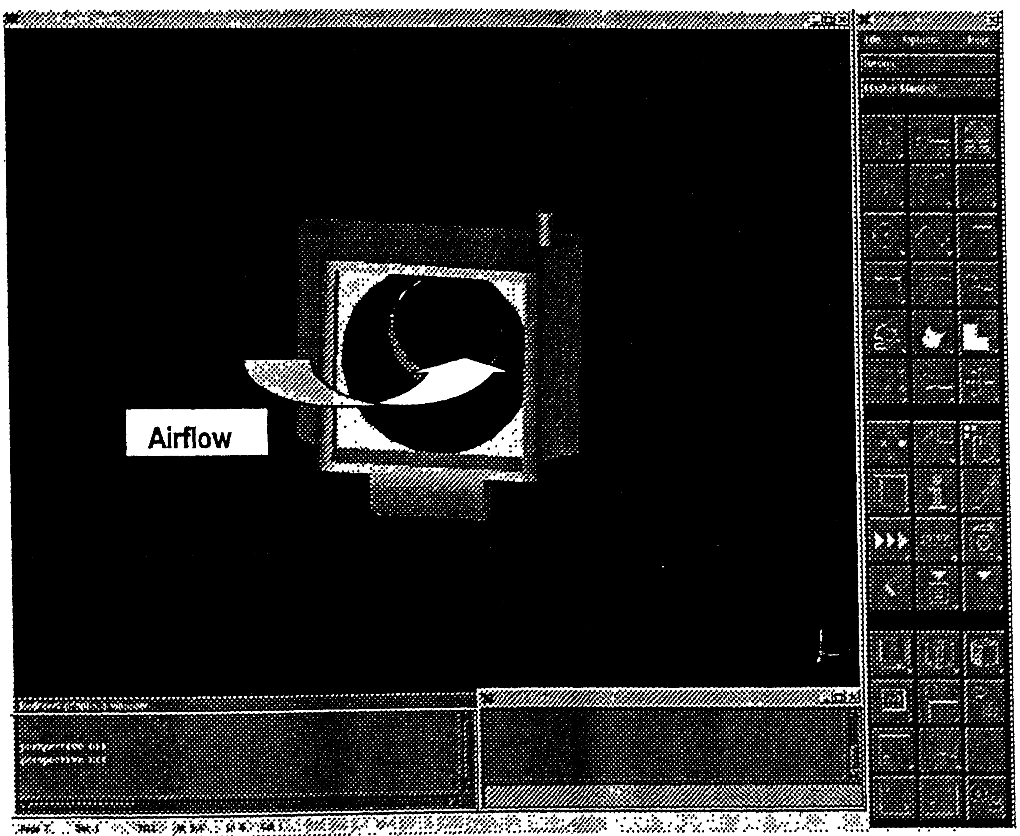


Figure 6.5 I-DEAS output of the solid model showing front view

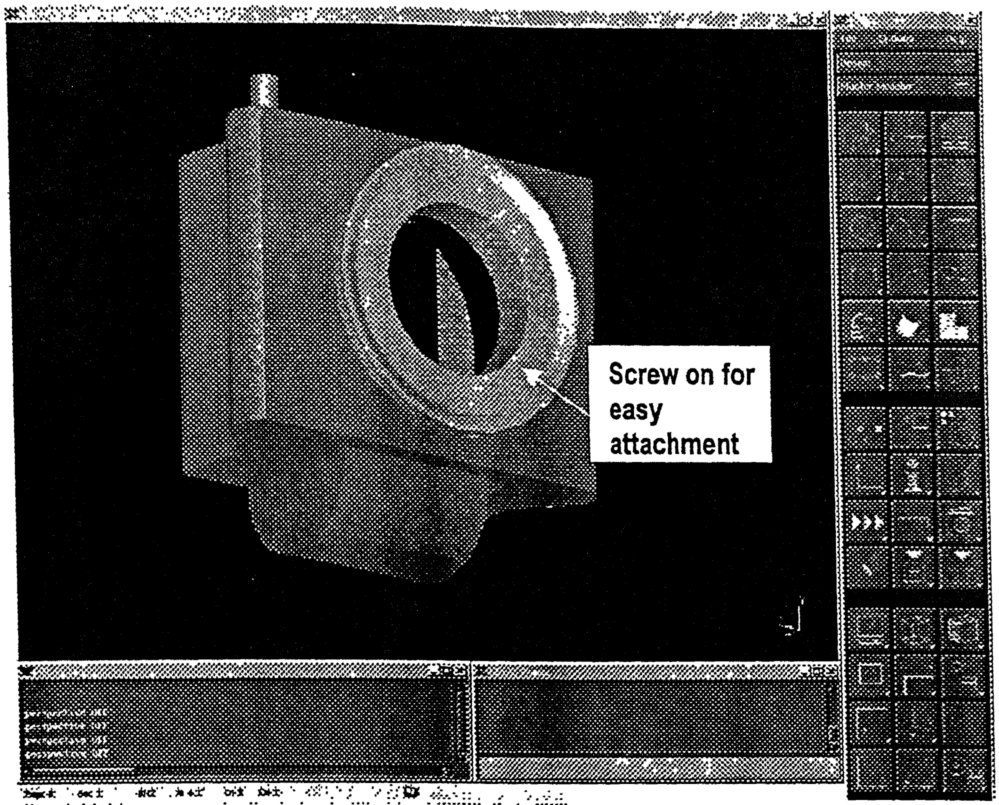


Figure 6.6 I-DEAS output of the solid model showing back part of the model

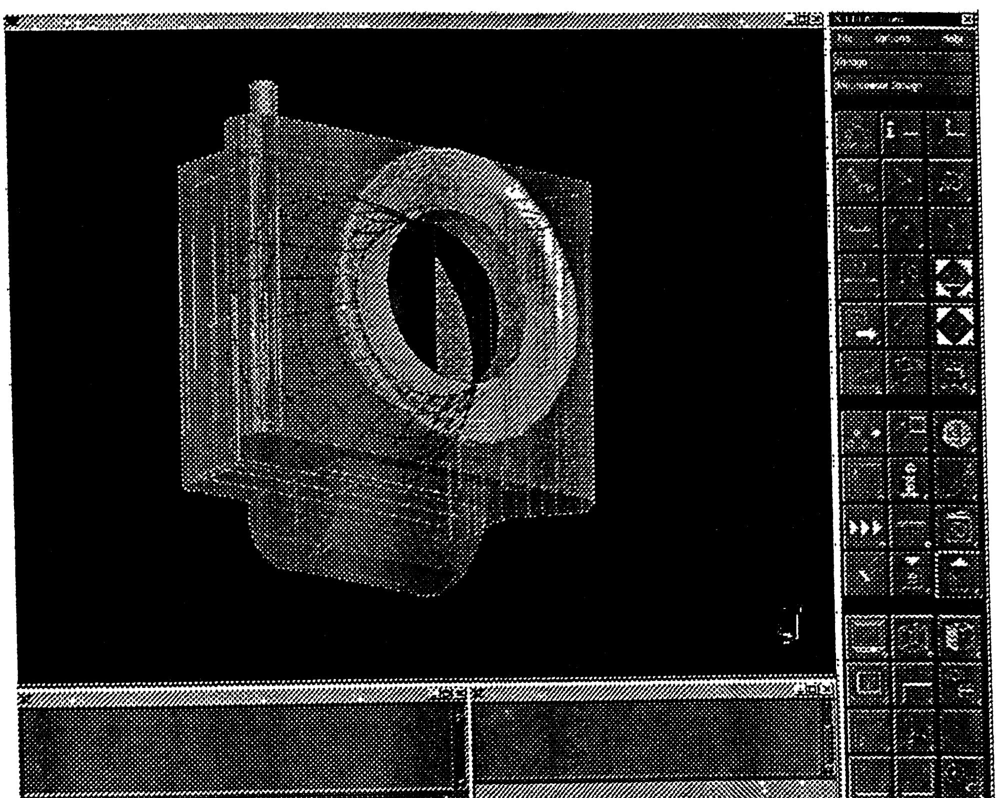


Figure 6.7 I-DEAS output of the solid model showing also the wireframes of the model

6.4 Development of filter material and its incorporation in design

After trying unsuccessfully in depositing activated charcoal on the filter fabric it was clear that one was reaching the dead end. Realizing this, a fresh approach was again adopted and finally the solution was surprisingly simple. Why not activate the whole filter fabric as the fabric basically consists of carbon molecules in chains? This approach had big advantages as the surface area would be more and also the pressure drop would be lot less. Also the regeneration will easy as the filter material will possess electrical conductivity.

6.4.1 Activated carbon cloth

Activated carbon is similar to crude graphite--the material used in pencils. Along with diamonds, activated carbon and graphite are both forms of carbon and contain almost no nitrogen, hydrogen, halogens, sulfur or oxygen. From a chemist's perspective, activated carbon is an imperfect form of graphite. This imperfect structure results in a high degree of porosity and more than a million-fold range of pore sizes, from visible cracks and crevices to gaps and voids of molecular dimensions. Porosity is what distinguishes activated carbon and makes it "activated."

Intermolecular attractions in the smallest pores result in adsorption forces. Carbon adsorption forces work like gravity, but on a molecular scale. They cause a reaction similar to precipitation, in which adsorbates are removed from solution or vapor stream. To develop a strong adsorption force, either the distance between the carbon platelets and the adsorbate must be decreased (by reducing its pore size), or the number of carbon atoms in the structure must be increased (by raising the density of the carbon). Physical adsorption enables activated carbon to remove taste and odor-causing organic compounds, volatile organic compounds (VOCs), trihalomethanes (THMs) and other halocarbons from process water and vapor streams.

Activated Charcoal Cloth (ACC) is a family of activated carbons in the form of cloth. These products are fundamentally unique in several important ways relative to traditional forms of activated carbon and relative to other filtration media that incorporate small particles of activated carbon.

Compared to other forms of activated carbon, ACC products are both similar and dramatically different. ACC is pure activated carbon which has the same high capacity for adsorption of organic compounds and other odorous gases as does high quality granular or powdered activated carbon. ACC will perform the same function - purification. separation or concentration of liquids and gases. ACC can be impregnated to enhance chemisorption capacity for selected gases. ACC can be regenerated to restore capacity without damaging the pore structure. The dramatic difference comes from the form of this activated carbon. ACC is a woven or knitted fabric and as such has many advantages over using loose granules in beds or small particles attached to another support media.

By being constructed of bundles of activated carbon filaments and fibers in woven form, several important advantages are imparted to ACC. The rate of adsorption is dramatically increased. Gases and liquids can flow through the fabric and retain the advantages of mass transfer zones obtained with filter beds. Faster adsorption rates mean smaller adsorption equipment and less carbon on line by as much as twenty-fold. At high air flow and short contact time, effective adsorption performance is achieved during the adsorption cycle. The carbon fiber is approximately 50 microns in diameter, so the kinetics for ACC products are similar to that of a 300 mesh carbon particle.

Because of the continuous and graphitic nature of the threads, ACC is electrically conductive. The woven and knitted forms allow effective and rapid electrical regeneration. The electrical conductivity of this activated carbon combined with its thin and flexible form makes is useful in electrical devices.

The continuous threads within the cloth also result in superior thermal conductivity properties, compared to carbon felt or granular carbon systems. Ignition and exotherm concerns are essentially eliminated. Unfortunately, due to inability to access atmosphere controlled furnace capable of taking high temperatures to the range of thousand degrees and above despite the literature survey the activated carbon clothe could not be prepared here. But the activated carbon cloth manufactured by HEG ltd. India was used. This cloth was further coated with glycerol to increase its particle capture and retention efficiency.

Physical properties of the filter cloth obtained is given in table 6.1.

Table 6.1 properties of activated carbon fabric supplied by HEG ltd.

Properties	**ACF2**
S_{BET} m^2g^{-1}	1201-1600
Pore Volume (ccg^{-1})	0.55-0.75
Effective Pore Size (^0A)	<10
Gram per Sq.Mtr (gsm)	85-215
Decomposition Temp (^0C)	500

6.4.2 Activated carbon cloth strip design

The problem with conventional anti-pollution masks is that as soon as the filter element is exhausted whole body has to be thrown away. In some masks the additional filter elements are supplied but the replacing the filter element is still a tedious and specialized job and require great skill on the part of the user. One solution that was identified was to use a strip like mechanism which would be rolled across the air path as soon as it was exhausted; a mechanisms quite similar to the one used by modern camera. This solution has following advantage: -

1. Makes the overall design simple and elegant.
2. Makes the filter replacement easy.
3. Reduces chances of injury to the filter fabric.

But the activated carbon cloth supplied had poor mechanical strength. When the user is rolling the fabric film, any concentration of the stress is like to result in the tearing of the fabric leading to the failure of the air purifier.

To overcome this problem following solution was proposed. The filter is embedded in a strip of adhesive plastic film, in form of discontinuous circular pieces (fig 6.8). The exposed diameter of the filter is 30mm and the total width of the filter is 40 mm with the center to center distance of the circular filter fabric patches being 45mm. The additional stresses generated accidentally will be taken up by the adhesive plastic film, which will prevent the filter fabric from tearing up.

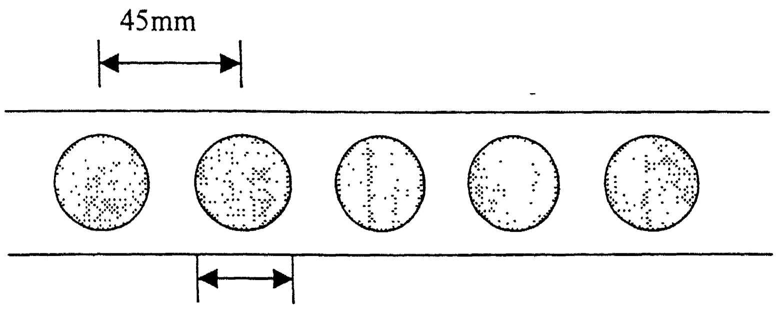


Figure 6.8 Activated carbon cloth filter strip

6.5 Material of the air purifier body

Materials must be selected with the right properties to meet design, economic, and service conditions. As the final body must be light and no case weight more then 100g so the material for the body of the air purifier has to be some kind of plastic. Most of the competitive products available use plastic as the body material.

Plastic materials must be chosen with care, keeping the final product use in mind. The properties of plastic depend more on temperature that do other materials. The final material choice for a product is based on the most favorable balance of design, fabrication, and total cost or selling price of the finished item.

Some of the desirable properties of the body of the air purifier were identified as:-

Table 6.2 Desirable properties of the body material

Desired Properties	Remarks
Tough surface characteristic	Because it would be exposed to outside conditions, which may induce scratching along with the outer body of the helmet, so tough surface characteristic is required.
Good surface aesthetics	Because we would like to have some design printed or some texture on the surface to give it an attractive look
Light, heat and UV stabilized	This is necessary as the service conditions include harsh environmental conditions.
Ability to take impact	Although the part is not designed to take the type of stresses coming onto the full face helmets during crash, yet it should be able to take some amount of impact.
Weight	It should be lightweight, but being lightweight it should not compromise on above listed properties.
Little effect of humidity and water	Least affected by environmental factors.
Easily mould able by injection molding	So that the production is economical as well as the dimensional accuracy of the produced parts are not compromised.
Reasonable cost	The cost of the body should not be more than the 5-10% of the total component cost as is the norm today in case of low priced gadgets.

The characteristics listed in the above table were taken and a comprehensive software known as CAMPUS 4.0 (Computer Aided Material Preselection by Uniform Standards) is a database which provides comparable data of different polymers from a variety of suppliers and it does include a standard set of practical properties considered useful for the material preselection process. CAMPUS .was used to find out about the ideal plastic, which would satisfy all or most the above conditions (fig 6.9).. Finally a COYOCA grade of ABS family was selected (Appendix E), manufactured by GE plastics.

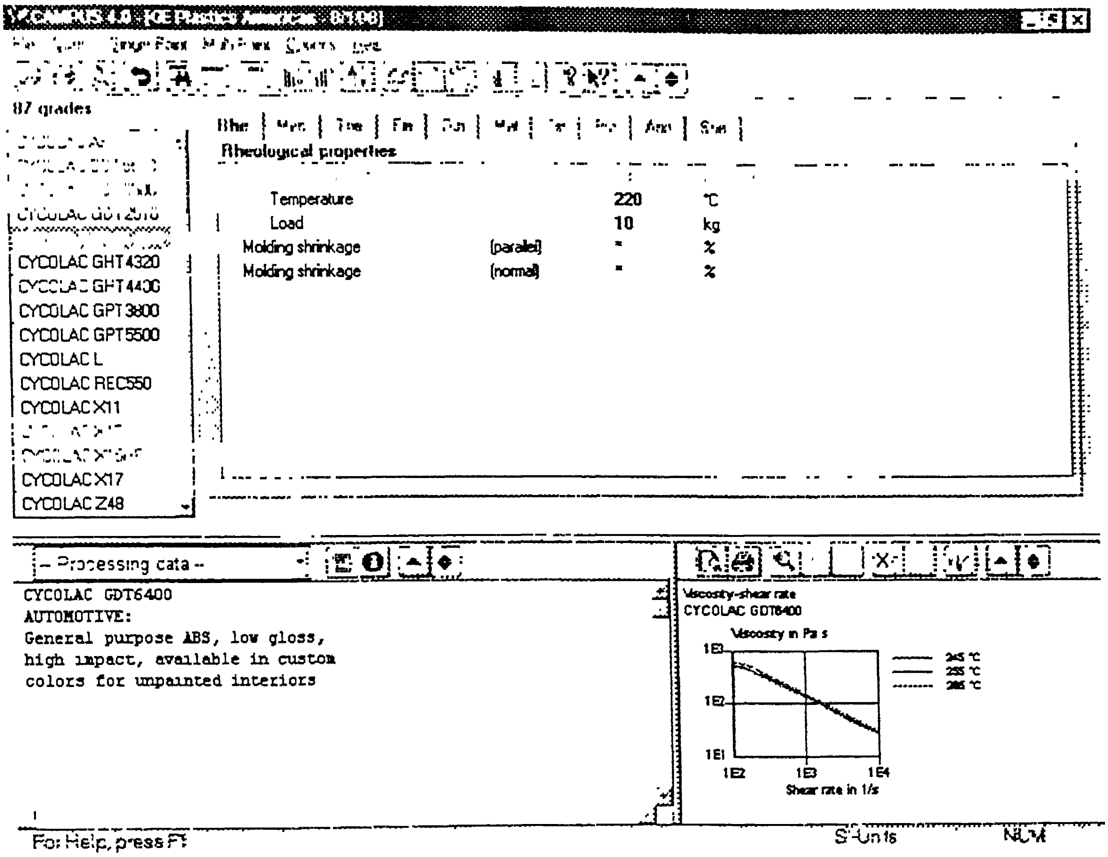


Figure 6.9 CAMPUS 4.0 used for material selection.

6.7 Final Design description and unique features incorporated

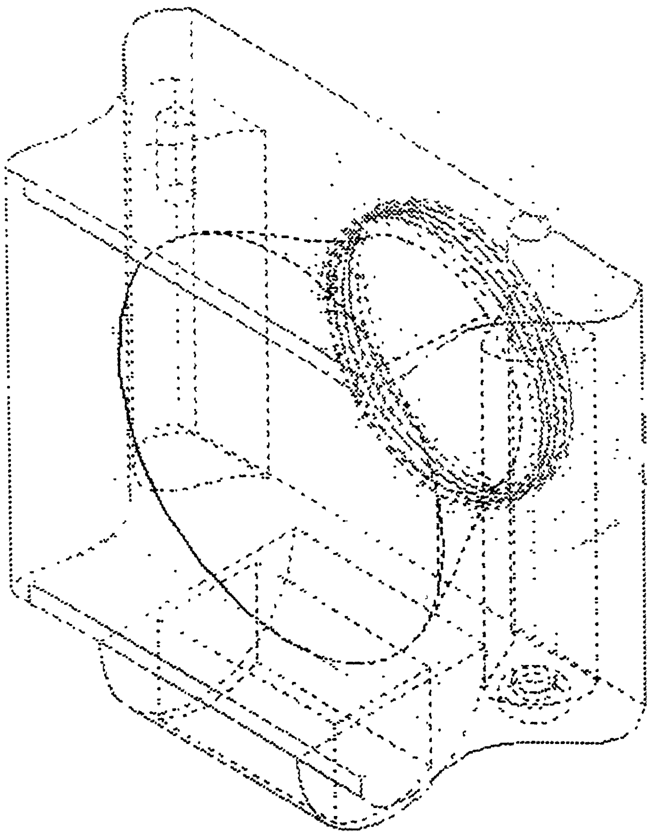


Figure 6.10 Final figure without the fan attachment and filter strip

- Forced air flow using a special fan having dimensions 50mmX50mmX10mm
- A device that is able to switch on and off at interaction using a switch
- Increased flow velocity to provide relief to consumer even when cruising through curved profile
- Low cost of operation of filter
- Low cost of components overall
- Small in overall size with total device having dimensions of 70mmX60mmX40mm

- Able to fit in all the helmet sizes and model variations
- High Gaseous contaminants removal with ACF
- High particulate removal efficiency, which increases with time
- Lower pressure drop across the filters with use of total filter fabric thickness of 8.5mm
- Less battery/current required/efficient
- Easy to change filter charge with the use of unique filter strip concept.

6.8 Design advantage over the existing design

The product offers the consumer advantages in two distinct ways:

1. The health advantage:

The consumer who has to suffer in the bad air quality all round the year which a daily average of close to two hours will be getting clean air at a very comfortable cost. Thus boosting productivity and lessening health problems and subsequent cost resulting in a clear profit to consumer. The solution is efficient and more effective than the conventional solutions currently available, is much more usable from consumer's viewpoint.

2. The circulation advantage:

Most of the helmets in India available are poorly designed with no regard for customer comfort in a hot country like India. As a result the Indian customer is highly frustrated lot and bemoans the lack of air circulation in the helmet, which ultimately subtracts from the ride quality. This also results in reduction in safety, resulting in more deaths and head related injuries. Our product has the advantage that it not only offers clean air free from most of the pollutants but also improves the air circulation to a very large extent. In fact one potential customer surprised us in our survey by responding that he will it buy even for the air circulation effect especially at intersections.

6.9 Testing of the Design

The experimental setup used for conducting experiments has been schematically shown in figure 6.11a and in figure 6.12.

Feed gas preparation

Carbon monoxide was generated in the laboratory by the dehydration of formic acid with sulfuric acid. This was achieved by dripping formic acid on sulfuric acid. By regulating the dropping rate of formic acid we controlled the flow of CO gas. The flow of air from the compressor was controlled by regulating valve, and it was mixed with CO gas to get the desired CO concentration.

HC was generated in the laboratory by bubbling the mixture of gasoline and groundnut oil in 1/5 ratio. As the vapour pressure of gasoline is too high groundnut oil was mixed. The bubbling was controlled by a pinchcock. Air was used as a carrier for the HC vapour and it was mixed the vapour to get the desired concentration of HC.

Testing features and operating conditions

A detailed description of the testing features and operating conditions of the present study are given in Table 6.3 and Table 6.4 respectively.

Table 6.3: Testing Features

Material	Activated carbon fabric coated with Glycerol
Glycerol used	5%-8% by weight of the ACF
Diameter of the exposed filter strip	30mm
Total depth of the filter strip	8.5 mm
BET surface area ACF used	1600 m^2g^{-1}

Table 6.4: Operating Conditions

Composition of feed gas	CO+HC+ mixed with air
Composition of CO	1.0% - 3.0% of air
Concentration of HC in feed gas	600ppm – 800ppm
Temperature	27°C ambient temperature
Flow Rate	5 LPM

Analytical Technique for CO and HC Estimation

The concentration of CO and HC in the gas mixture was measured by Auto Exhaust Gas Analyzer, (Model SAGEM-5040, SAGEM SOURIAU Systems, France) which is based

on the principle of nondispersive infrared (NDIR) absorption of radiation by polyatomic gases in the IR region of the spectrum (2-15 μm), which does not disperse spectrally. The natural frequency of molecular vibration lie in the region of spectrum and therefore absorption of radiation takes place at these specified frequencies.

Absorption occur according to the Beer-Lambert Law:

$$I_t = I_o^{-KLC}$$

Where

I_t= Intensity of transmitted light

I_o=Intensity of incident light

K= absorption coefficient of gas to be measured

L= Path length of the sample cell

C= concentration of gas to be measured

The IR source is heated filament, the stability of which is ensured by feeding power from a precision regulated DC power supply. Further this radiation is chopped with a mechanical chopper, which is driven by stepper motor. The detector used is of pyroelectric type, which generates an electrical signal when there is any change in the incident radiation falling on the surface. The chopped radiation falls on the pyroelectric detector and an AC signal of the frequency of chopping is obtained.

This signal is amplified and processed to get a DC signal that is then displayed on meter. The detector is thermostated at constant temperature to ensure stable performance of the instrument under varying ambient conditions. The entire optical path from IR source, sample tube, interference filter till the pyroelectric detector is coupled together to make it dust proof. The exhaust gas passes through the sampling tube and is laid into the drain separator cum filter arranged at the back panel of the analyzer unit. The 5 μm sintered bronze filter removes the dust particles from the gas stream. The sample then enters the sample tube and the flow is then read on the rotameter. a compact, double diaphragm type pump is used to first draw the sample up to the analyzer at high flow rate and then lead a part of the gas sample in to the analyzing system at a flow rate of 0.6 LPM.

The results of the HC and CO removal are given in the figure 6.11d. The efficiencies obtained match with the efficiencies provided, so the coating of the glycerol does not have a significant effect on adsorption.

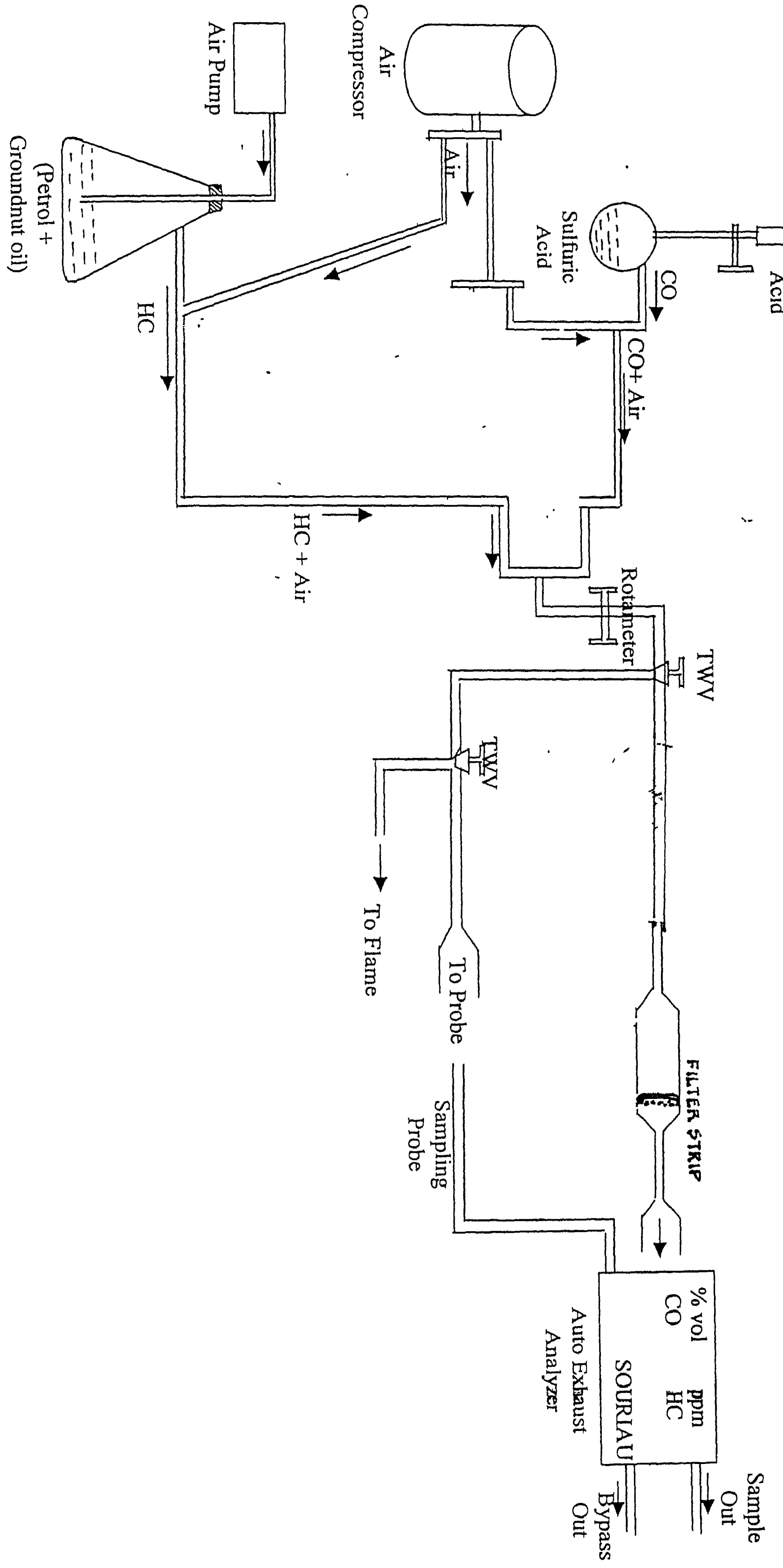


Figure 6.11a Setup for measurement of HC and CO

Particulate removal test

For testing, ideally a dust chamber would have been suitable. But after the failure of the dust chamber built, the particulate removal test were conducted in ambient air at Naveen market intersection. Instrument used was handy sampler by *Envirotech.* A Y junction was used to take the both the air filtered through filter strip as well as the ambient air. The particulates were captured on glass mircofiber filter with a diameter 2.5cm (*GF/A, Whatman*). After a designated hour the both filters was taken out and weighted. The difference from the original weights gave the weight of the particulate deposited. From this removal efficiency was computed. The results are shown in the figure 6.11c.

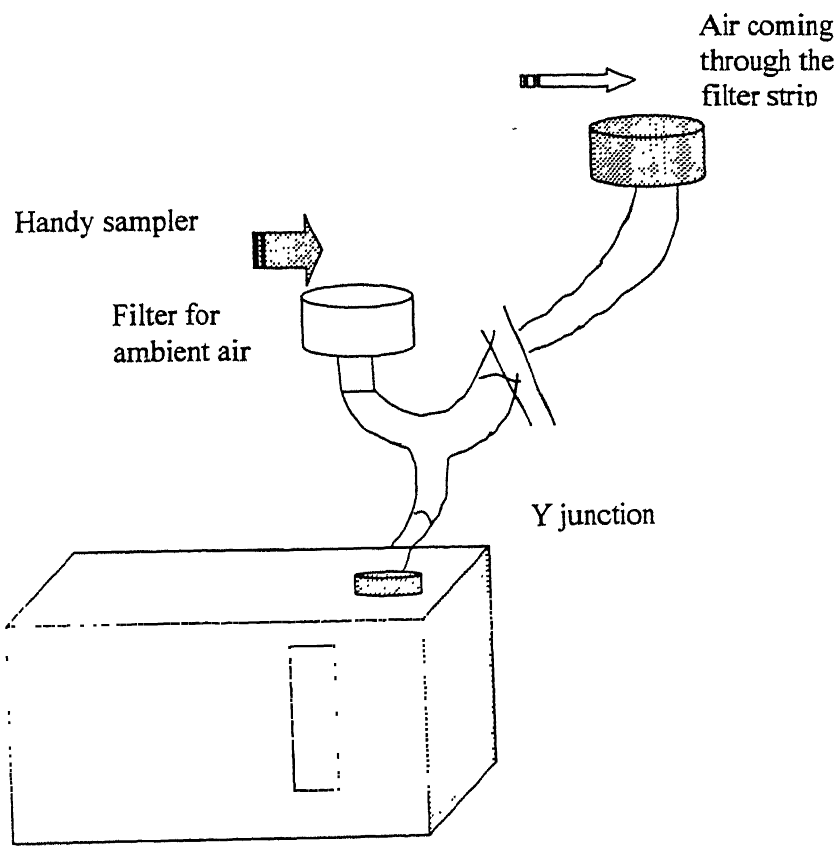


Figure 6.11b Setup for measurement of particulate capture efficiency

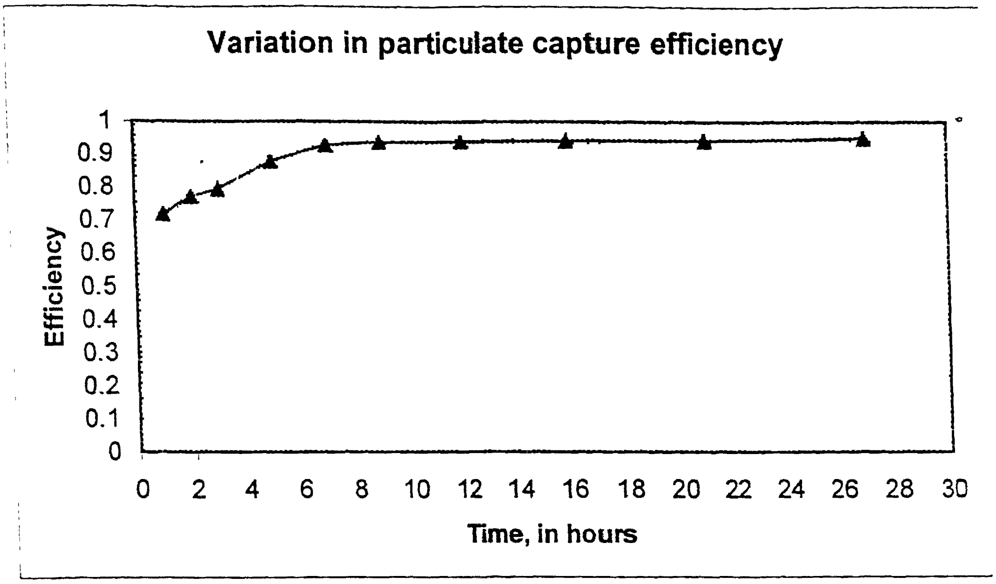


Figure 6.11c Variation of particulate matter removal efficiency of the filter with time

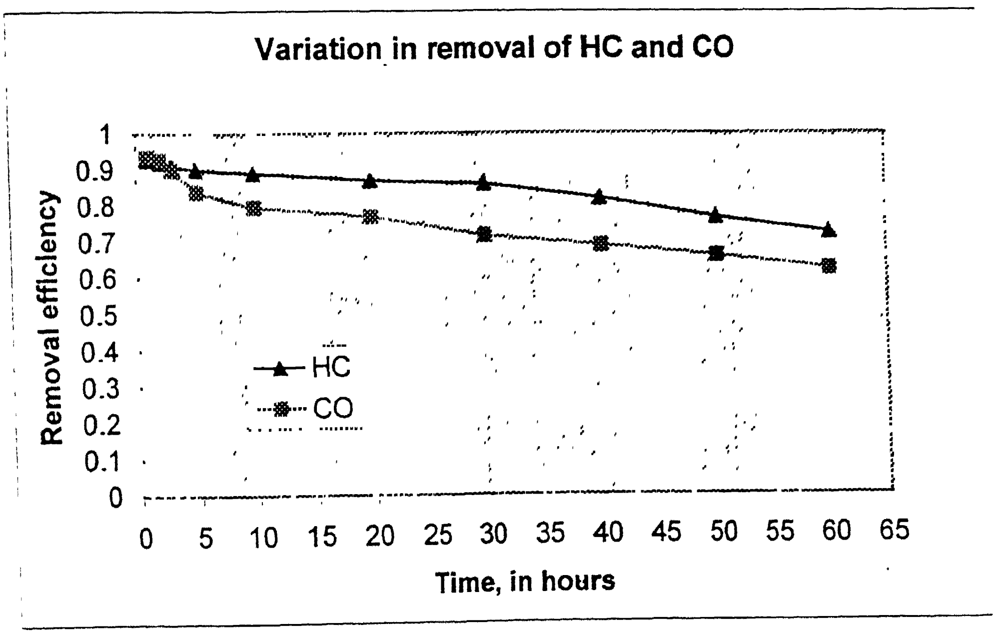


Figure 6.11d Variation of HC and CO removal efficiency of the filter with time

6.10 Cost analysis

Following cost estimates were generated by discussions with the suppliers of the major components. This estimation is based on the basis of the product being manufactured in or near the biggest market i.e. New Delhi.

Table 6.5 Manufacturing cost (in Indian Rupees):

Cost of the ABS casing	11
Cost of packaging	4
Cost of the Fan	25
Cost of the filter supplied with the unit	30
Cost of the battery	50
Assembling cost (inclusive of labour cost)	10
Total cost	130
Our margin	110
Wholesaler's margin	50
Retailer's margin	60
Retail price	350

Table 6.5a Filter cartridge details(Bigger):-

Basic material cost	50
Packaging cost	5
Assembling cost	15
Profit	45
Wholesaler's margin	20
Retailer's margin	30
Retail price	175

Table 6.5b Details of the filter cartridge cost(smaller):-

Basic material cost	30

Packaging cost	4
Assembling cost	10
Profit	20
Wholesaler's margin	15
Retailer's margin	20
Retail price	99

Note:- Above costs are estimated on the basis of figures supplied by the suppliers and current cost of equipments and thus on actual execution this may vary by a factor of +- 5% .

Chapter-7

SUMMARY OF DESIGN

The final design satisfies most of the design objectives that were identified by the customer as important. This design shall have the following important features:

1. Forced airflow using a special fan having dimensions 50mmX50mmX10mm. This fan will provide more airflow for good circulation of clean air during intersection, which was identified as one of the main design parameters.

2. A curved venturi profile of the air path through the air purifier to provide clean air during cruising.

3. Small in overall size with total device having dimensions of 70mmX60mmX40mm with the ability to fit in all the helmet sizes and model variations.

4. Device has reasonably high gaseous contaminant removal with filter charge using ACF coated with glycerol and high particulate removal efficiency, which increases with time.

5. Uniquely designed easy to change filter charge with the use of unique filter strip concept, this will allow the user more usability with less amount of effort.

6. Economical in total cost and running cost as compared to the existing devices and thus having global applicability where the conditions similar to Indian metro cities exist, like in south east Asia.

Chapter-8

SCOPE OF FUTURE WORK

Although the final design has realized most of the goals, it still falls short in some areas where in the future some work may be done.

7. Testing of the device in real world environment and recording of air quality parameters before and after its usage.

8. Reliability testing of the device with a view to make sure that it performs in all types of condition with a reasonable degree of success with regard to pollutant removal.

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APPENDICES

Appendix A

Consumer survey form

Note- The personal details provided by you will not be used unethically for purpose other than explained to you.

1.Personal Details

Sex: Male ☐ Female ☐

Age (years)		*Occupation*		Monthly Income	
15-25	☐	Govt. Service	☐	<5000/-	☐
25-35	☐	Pvt. Sector	☐	5000-10000/-	☐
35-45	☐	Business	☐	10000-15000/-	☐
45-60	☐	Student	☐	15000-25000/-	☐
60>	☐	Others	☐	>25000/-	☐

2. *The Position during commuting* : Rider ☐ Pillion ☐ Both(depending upon occasion) ☐

3. *The time spent traveling daily approximately*

   <45 minutes ☐ 45-60 minutes ☐ 60-90 minutes ☐ 90-120 minutes ☐

4. *You enjoy wearing helmet.*

   Can't Tell ☐ Strongly disagree ☐ disagree ☐ ☐ agree ☐ strongly agree

5. *How many days do you spend on average traveling on the road*

   0-100 ☐ 100-150 ☐ 150-200 ☐ 200-250 ☐ <250 ☐

6. *The average air quality during commuting is bad (visually as well as physical response)*

   Can't Tell ☐ Strongly disagree ☐ disagree ☐ agree ☐ strongly agree ☐

7. *Products used to protect yourself against bad air quality*

   None ☐ Pollution mask ☐ Handkerchief ☐ Some other product

8. How much are you willing to pay for effective, comfortable and easily useable pollution protection measure(in Rs)

0-50 ☐ 50-200 ☐ 200-300 ☐ 300-400 ☐ 400-500 ☐ >500 ☐

9. Tick the relevant information which you perceive to be true

a) **Major reason for commuting**

1.Going to work place ☐

2.Shopping and entertain ☐

3.Going to college/school ☐

b) **The common experiences with helmet that you have**

1.Poor visibility ☐

2.Uncomfortable in sum ☐

3.Air circulation is bad ☐

4.Given a chance you would not wear one ☐

c) **Symptoms experienced during and after commuting**

1.Irritation in eyes ☐

2.Chocking feeling in airways ☐

3.Nausea at intersections ☐

4.Headache ☐

5.Difficulty in breathing ☐

Appendix B

Design calculation for iteration 2:-

Design of the filters:

Activated carbon filter:

Activated carbon is a nonpolar adsorbant and thus is very effective in adsorbing most of the gaseous pollutants produced as a result of inefficient combustion.

To affect the good engineering design of an activated carbon adsorption system, it is first necessary to obtain the following data:

1. The actual amount of the air to be processed by the adsorbed; in this case it is the amount of air an average person consumes which is between 3 to 5 liters of air per minute.
2. The temperature of the gas, in this case the temperature of the ambient air stream is within the maximum efficiency range of the activated carbon.
3. The materials to be adsorbed , in this case they are mostly non polar compounds for which activated carbon is having very high affinity thus also it can also work very one well in humid environment.
4. The concentration of the material to be adsorbed , in this case as the worst air quality case for the designing purpose I have used the data generated by the CPCB air quality monitoring station at ITO-New Delhi(The maximum level of combined NO_x and SO_2 is 120 $\mu g/m^3$).

<u>CALCULATIONS</u>

The weight of the adsorbent required is then determined using the following equation[1]

$$W = (T\ E\ Q_r\ M\ C_v)/ 6.43\ (10)^6\ S$$

Where;

[1] Turk . A. Air Pollution Handbook, A. C. Stern , Editor (New York: Academic Press, 1969)

T= duration of adsorbent service before saturation (hr)= one year = 8764 hours.

E = sorption efficiency (fractional)= taken to be equal to 1.0

Q_r = air flow rate through the sorbent bed(ACFM) = 37.07×10^{-3}

M = average molecular one weight of the sorbed vapor = 48 [2] (average value)

C_v = entering vapor concentration(ppm by volume) = 2

S = proportionate saturation of sorbent (fractional) = 0.8

Putting in these values,

W= 0.0059 kg

The volume of carbon required based on the bulk density of the carbon which is equal to 0.7g/cm^3

V= W/d

Where d= bulk density of carbon(average density as one are impregnating carbon into the foam one don't know its true bulk density that one will determine only after making it)

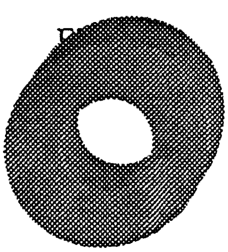
V= 5.9/.7 = 8.42 cm^3

Let the activated carbon filters be provided as the 2 disks of 5 cm diameter

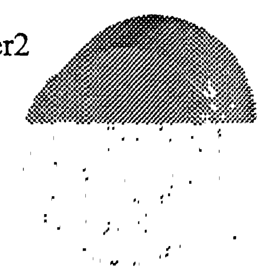
Then total area of the filter = $2\ (\pi/4)\ (5)^2$

$$A = 39.263\ \text{cm}^2$$

Height of the bed h= 8.42 /39.263 =0.21 cm = 0.4 cm (say)



filter2



HEPA filter

HEPA filters are at the heart of clean air systems in a wide range of applications in high technology manufacturing, science and health care. They are also known as

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[2] Turk . A. Air Pollution Handbook, A. C. Stern , Editor (New York: Academic Press, 1969)

'absolute' filters, and one re developed during WORLD WAR II for the arrestance of radioactive particles in the nuclear industry. Since that time , significant developments have been made in order to meet increasing demands for higher efficiency against smaller particles.

A conventional HEPA filter consists of a continuous sheet of a special paper-like, glass-fibre filter medium which is pleated into a vee configuration with corrugated aluminium separators between the pleats. This forms the filter element, which is then bonded into a rigid frame using a special polyurethane compound. Standard filters are produced in a range of face dimensions and in two standard depths of nominally 150 mm and 300 mm.

Another type of construction is used for 'minipleat' filters, which are produced in depths down to 50 mm. They have very close pleating of the filter medium, and manufacturers use various separation techniques to create minimal spacing between the pleats. However as we are miniaturising the whole thing will have to be made by ourselves. We are using this type of the HEPA filter having a square surface area of 5 cm X 5 cm with the depth of 2 cm. The pressure drop for this filter is about 200 Pa which is comparatively less.

PRESSURE DROP CALCULATION

Total pressure drop is given by;

ΔP = pressure drop in the activated carbon filter(P1) + pressure drop in the HEPA filters(P2)

P1 = h (pressure drop per unit length as per the performance curves)

In the foam impregnated activated carbon filter the head loss is minimal as the there are enough voids to reduce it.

Pressure drop per unit length= 20 Pa/cm (say generally it is less than this)

So ;

P1 = (0.4)(20) = 8 Pa

In HEPA system;

Total pressure drop before breakthrough occures;

From rating curves provided by Austinair (USA 's biggest HEPA filter manufacture) ;

P2 = 200 pa (for the minipleat HEPA filter) However for our low flow rate the pressure drop will be lesser.

Total pressure drop = 8 +200 = 208 pa

Now providing for the nominal head loss occurring in the bends and obstructions etc., providing a multiplication factor of 1.5

Total pressure drop = 315 pa

Power loss suffered due to this pressure drop = $\Delta P (Q_r)$ = 0.026 Watt

Applying a factor of safety /ignorance of magnitude 2

Power loss that must be provided by the fan = 0.052 watt = .052 J/s

This power will be provide by the fan to push the air through the filters. As such one can calculate the battery requirement of this system assuming an efficiency of the power transfer as 0.8.

Thus the battery will have to supply 0.065 watt which is feasible by providing two pencil rechargeable cells of 1.5 V commonly available.

Fan calculations:

One can either procure the fans directly that provide us the required amount of pressure difference generation or make the fan ourselves.

This fan is of the size 40 X 40 X 7 (all dimensions in mm)

Voltage: 5 / 12 VDC

Airflow: 4.5 - 5.9 CFM

Air Pressure: 1.6 - 2.5 mm-Aq

Weight: 11 g

Other option is to assemble one oneself.

In this one can use a small motor of 1.7 v which is used in the walkman . This motor is 1.5cm thick and so total dimensions of the fan including the motor will be 4.5cm X 4.5cm X 2 cm .

The usual speed of the walk man motor is around 1400-3000 rpm. Using this to calculate the flow that will be generated.

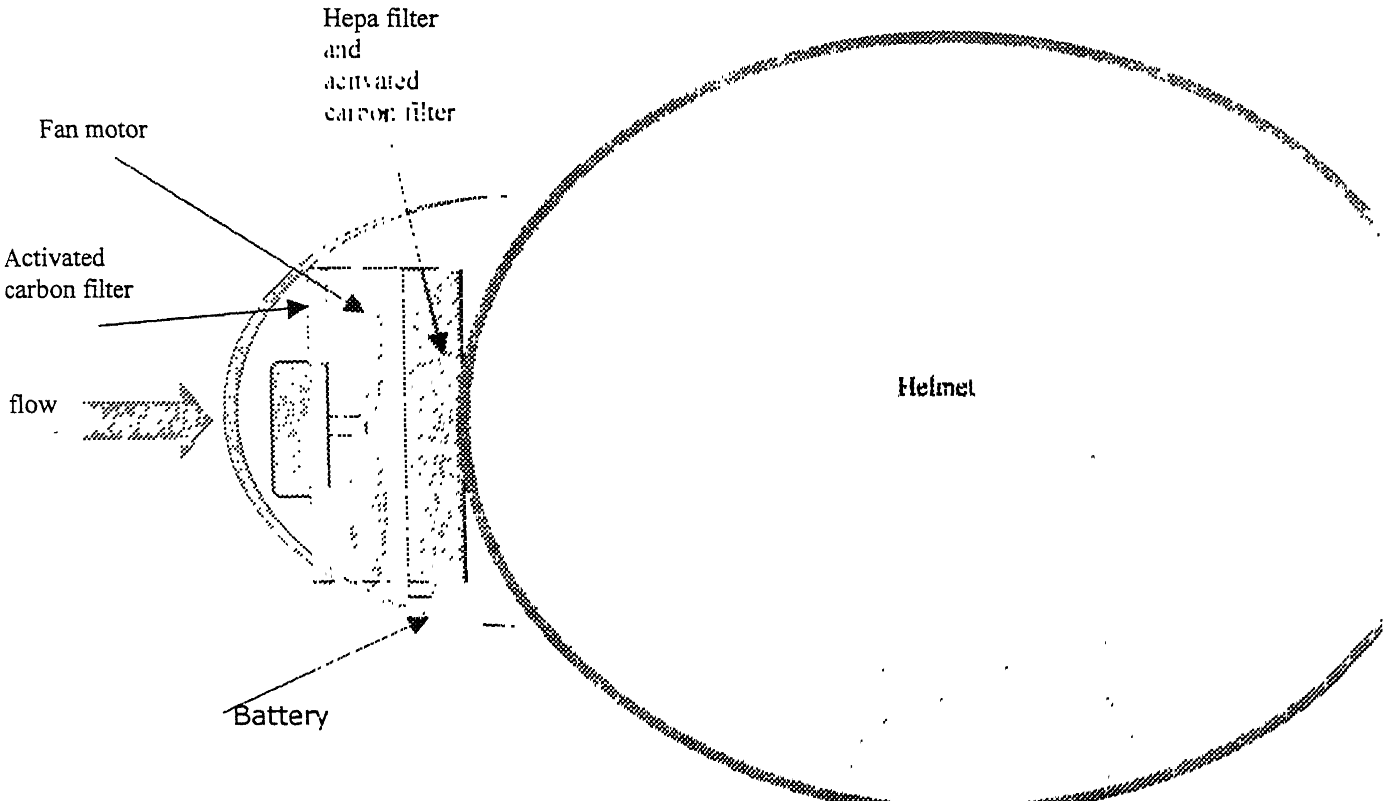
Effective projected area X volumetric flow rate = speed of the fan

$\pi/4\ \{(0.045)^2 - (0.025)^2\} \times Q = \pi DN/60 = \pi (0.045)1400/60$

$Q = 50$ l/min .

As one needs only 5 l/min this gives us a factor of safety of 10.

But the first option was exercised so as to reduce time and effort.



Top view of schematic design proposed for iteration 2

Appendix C

Properties of Glycerol

Properties	Behavior	Remarks
Physical data	- Appearance: colorless liquid - Boiling with decomposition: 290 c (554 f) - Vapor pressure: negligible - Evaporation rate (n-butyl acetate = 1): negligible - Volatile fraction by weight: negligible - Specific gravity (water = 1): 1.26 - Solubility in water: appreciable	Its viscosity is much higher than water but surface tension of water is more. This is significant because it is hygroscopic and thus this may increase particle capture as well as particle retention. Also the air passing through it carries a reduction in temperature and introduction of sweet smell.
Toxicity and health hazard data	a. Exposure limits: tlv 10 mg/m3, 8-h twa (mist), ACGIH, 1989-90. OSHA PEL 10 mg/m3 (mist), 1989. b. Exposure effects: Inhalation: low hazard for usual industrial handling. Skin: low hazard for usual industrial handling. Eye: no specific hazard known. Contact may cause transient irritation. Ingestion: expected to be a low ingestion hazard.	This data is significant because of determination of problem of toxicity and health hazard if any. However very less concentration used here does not pose any problem.

Ventilation and personal protection	Ventilation and respiratory protection: Good ventilation* should be sufficient. Supplementary ventilation or Respiratory protection may be needed in special circumstances. * Typically ten room volumes per hour is considered good general Ventilation; ventilation rates should be matched to conditions of use.	This is mainly needed for industrial environment where the threat perception is higher due to the higher concentration present.
Skin and eye protection	Safety glasses recommended in industrial operations involving chemicals. if prolonged or repeated skin contact is necessary, gloves or other Protection may be required	Again not of much significance due to low concentration.
Special storage and handling precautions	Keep from contact with oxidizing materials. Keep container tightly closed and away from acetic anhydride.	None

Appendix D

To reach the final design, each iteration was tested with some simple experiments designed to give both qualitative as well as quantitative results. These results then formed the backbone of the feedback generated.

Name of the experiment	Brief description of the test
1.Experiments to determine the optimal dimension and shape of the filter	This test will involve flow measuments with various sizes and shapes of filter to obtain the right dimensions
2. finding of optimal distance of the filter for lowest pressure pressure loss	For this test we will have to take the reading at various x values , and the value which gives the lowest pressure loss will be retained
3. streak test to determine the flow direction test	In this test carbon black will be introduced with the flow to determine the exact flow pattern and carryout modifications in the design on its basis
4.Effect of curvature on the flow	In this test we will be using the above procedure but will try to use circular filter instead of cubical one
5. Efficient prefilter placement	In this we will be introducing the filter and we will determine the optimal placement of the filter and also the thickness of the prefilter giving lowest pressure loss
5. VOC test on prefilters for determination of efficiency of VOC removal with respect to time	In this we have some standard test for determining removal of HC and CO , using the gas analyzer.
6. DOP test to determine the efficiency of HEPA filter with respect to time and also the removal particle size	This is the standard test to determine the removal efficiency of the HEPA filter. But as the filter flow rate is very low the standard test can't be used rather a modified version was used to gather qualitative data.

7.Dust holding efficiency test also known as the service life test	In this test we determine the dust holding capacity of the filter (pressure drop across the filter rises as the dust is fed)
8 Energy requirement of the filter	In this test we will calculating the mean energy consumption through experimental data over a period of time
9. Operating limitation and hazards	The threat to reliable air filter operation are high temperatures, excessive air velocity and filter resistance, wetting, vibration and corrosion.
10. Weight balancing test	This test will be done so that extra moment due to the weight is not causing any problem to the user
11. Visual test including the ergonomics	This test will be done to determine the exact dimensions of the filter and color coding to incorporate the ergonomics into the design

Appendix E

Output of the material selection program run

Product text

```
CYCOLAC AR
AUTOMOTIVE:
General purpose ABS, high impact, good flow,
good surface aesthetics
```

Processing data - Injection molding

```
PREPROCESSING
Predrying Conditions
  Temperature        :  80 -  95 °C
  Time               :    2-4    h
  Max. water content :    0.1    %
PROCESSING
Cylinder Temperature
  Rear   zone        : 190 - 205 °C
  Middle zone        : 210 - 225 °C
  Front  zone        : 225 - 245 °C
  Nozzle             : 230 - 260 °C
Melt  temperature    : 230 - 260 °C
Mold temperature     :  50 -  70 °C
```

Rheological properties

Melt volume-flow rate		19	cm3/10min
Temperature		220	°C
Load		10	kg
Molding shrinkage	(parallel)	*	%
Molding shrinkage	(normal)	*	%

Mechanical properties 23°C/50%r.h.

Tensile Modulus	(1mm/min)	2560	MPa
Yield stress	(50mm/min)	54	MPa
Yield strain	(50mm/min)	-	%
Nominal strain at break	(50mm/min)	30	%
Stress at 50% strain	(50mm/min)	-	MPa
Stress at break	(5mm/min)	-	MPa
Strain at break	(5mm/min)	-	%
Tensile creep modulus	1h	-	MPa
Tensile creep modulus	1000h	-	MPa
Charpy impact strength	+23°C	110	kJ/m²
Charpy impact strength	-30°C	81	kJ/m²
Charpy notched impact strength	+23°C	15	kJ/m²
Charpy notched impact strength	-30°C	8	kJ/m²
Tensile notched impact strength	+23°C	-	kJ/m²

Thermal properties

Melting temperature	(10°C/min)	-	°C
Glass transition temperature	(10°C/min)	106	°C
Temp. of deflection under load	(1.80 MPa)	79	°C

Temp. of deflection under load	(0.45 MPa)	88	°C
Temp. of deflection under load	(8.00 MPa)	*	°C
Temp. of deflection	(see ISO 75-3)	*	°C
Vicat softening temperature	(50°C/h 50N)	100	°C
Coeff.of linear therm. expansion	(parallel)	0.7	E-4/°C
Coeff.of linear therm. expansion	(normal)	0.7	E-4/°C
Flammability UL94 at 1.6mm nom. thickn.		HB	class
Thickness tested		1.5	mm
Yellow Card		REG	-
Flammability UL94 at thickness h		-	class
Thickness tested		-	mm
Yellow Card		-	-
Flammability UL94 5V at thickness h		-	class
Thickness tested		-	mm
Yellow Card		-	-
Oxygen index		-	%

Electrical properties 23°C/50%r.h.

Relative permittivity	100Hz	-	-
Relative permittivity	1 MHz	-	-
Loss factor	100Hz	-	E-4
Loss factor	1 MHz	-	E-4
Volume resistivity		-	Ohm*cm
Surface resistivity		-	Ohm
Electric strength		-	kV/mm
Comparative tracking index		-	-

Other properties

Water absorption		-	%
Humidity absorption		-	%
Density		1050	kg/m3

Material specific properties

Viscosity number		-	cm3/g
Indicative density	(PE only)	-	kg/m3
Isotaxy Index	(PP only)	-	-

Test specimen production

Processing conditions acc. ISO	2580	-
Injection Molding, melt temperature	250	°C
mold temperature	60	°C
injection velocity	200	mm/s
hold pressure	40	MPa
Compression Molding, mold temperature	-	°C
cooling rate	-	K/min
molding time	-	min
demolding temperature	-	°C

Processing and delivery form

Injection Molding	+
Film Extrusion	-
Profile Extrusion	-
Sheet Extrusion	-
Other Extrusion	-
Coating	-
Blow Molding	-
Calendering	-
Transfer Molding	-
Casting	-
Thermoforming	-
Pellets	+
Granules	-
Powder	-

Additives

Blowing agent	-
Lubricants	+
Antiblocking agent	-
Release agent	-
Metal deactivator	-
Flame retarding agent	-
Plasticizer	-
With fillers	-
Without fillers	-

Special Characteristics

Transparent	-
Increased electrical conductivity	-
Anti-static	-
Flame retardant	-
Platable	-
High impact or impact modified	-
Light stabilised or stable to light	-
U.V. stabilised or stable to weather	-
Heat stabilised or stable to heat	-